

HDO and D₂O low pressure, long path spectra in the 600 to 3100 cm⁻¹ region. I. HDO line positions and strengths.

Robert A. Toth

California Institute of Technology
Jet Propulsion Laboratory
Pasadena California 91109

Tables 12

Figures 0

Abstract

High resolution spectra of gas mixtures of HDO, D₂O, and H₂O were obtained with a Fourier-transform spectrometer with path lengths up to 433m. The spectra were analyzed to obtain line positions and strengths of over 6000 transitions of HDO and D₂O. For HDO these included the (000)-(000), (020)-(010), and (100)-(010) bands of HD¹⁶O and the (010)-(000) bands of HD¹⁶O, HD¹⁷O, and HD¹⁸O. Several of these assignments are reported for the first time. Of interest was the extended coverage of the A-type transitions of the (010)-(000) band of HD¹⁶O. This is the only A-type infrared band of any of the water vapor species (HDO, D₂O and H₂O) that is not involved in interactions with other bands. By this token, the A-type dipole moment expansion matrix elements can be tested without involving perturbation theory. The measured line strengths of the interacting bands, (020)-(010) and (100)-(010), were analyzed using a full perturbation treatment. Strong localized Coriolis interactions affected only a few observed transitions.

1. INTRODUCTION

This investigation and a following one involving D₂O measurements are continuations of earlier studies covering the v₂ bands of HDO (1) and D₂O (2). The spectra analyzed in the earlier studies were obtained with absorption path lengths of 2.39 m or less whereas the path lengths used in the present investigation were 25m, 73m, 193m, and 433m. Many of the transitions observed in the present data were too weak to be observed or measured accurately from spectra used in the earlier studies (1,2).

Several of the measurements given in this report are presented for the first time which includes the following: pure rotational transitions above 600 cm⁻¹, high J and/or K_a transitions in the v₂ bands of HD¹⁶O, and lines of the "hot" bands, (020)-(010) and (100)-(010), of HD¹⁶O. Included but not reported in this study are new line position measurements of the (020)-(000) and (100)-(000) bands of HD¹⁶O in the 2545 to 3030 cm⁻¹ region. Analysis of these spectra were used in the present study as additional data for the determination of the upper state rotational energy levels using new calibration frequency standards. Previous HDO studies (3-5) in the 3.7 μm region gave line positions on the order of 3 to 5 × 10⁻⁴ cm⁻¹, higher than those measured in the present work.

2. EXPERIMENT

The spectra were recorded with a Fourier-transform spectrometer (FTS) located in the McMath solar facility at the Kitt Peak National Observatory. The experimental conditions of the

measurements are given in Table 1. The sample gases consisted of evaporation from a mixture of liquid H₂O and liquid D₂O and for samples used for the 7 μm runs, the amount of D₂O exceeded that of H₂O in order to minimize contributions due to H₂O absorptions. A 6-m base length multiple transversal cell was used in all of the lower frequency runs. This absorption cell was located about 5.5m from the entrance to the vacuum tank which enclosed the FTS. The optical path from the cell to the tank passed through another cell (2.39m in length) which was evacuated and the remainder of the path was open space purged with dry N₂. By this procedure, a large portion of atmospheric H₂O (due to room air) was removed from the path. The data covering the 3.7 μm region were obtained with the 2.39 m long glass absorption cell placed directly in front of the vacuum tank. The vacuum tank was continuously pumped with a residue pressure between 50 and 200 μm and even at these low pressures, added contributions due to the strongest transitions of the v₂ bands of CO₂ and H₂O were observed in the 600 to 2065 cm⁻¹ region. The frequency calibration of the 7 μm spectra was derived from previous reports on line position measurements of H₂¹⁶O (6), HD¹⁶O (1), and D₂¹⁶O (2), as well as CO₂ (7) (for the 600 to about 700 cm⁻¹ region).

Sample temperatures were inferred from readings of one or more thermistor probes in thermal contact with the absorption cell and all data were obtained with sample temperatures at or very near room temperature (296K). The total sample pressures were measured with a Baratron gauge whereas the HDO and D₂O partial pressures

were derived from measurements of the spectra and previously determined line strengths in the lower spectral region (1,2). The estimated uncertainties of the total pressure values given in Table 1 are about 0.5% whereas the estimated uncertainties for the HDO and D₂O partial pressures are about 1%.

The H₂O partial pressures of the samples were inferred from the relation:

$$P(\text{total}) = P(\text{HDO}) + P(\text{D}_2\text{O}) + P(\text{H}_2\text{O}), \quad (1)$$

where P represents the pressure. The H₂O pressures derived from eq. (1) and given in Table 1 represent the H₂O content in the absorption cell plus the small amount in the vacuum tank. Each of the stronger H₂O transitions (strengths $\geq 0.01 \text{ cm}^{-1}/\text{atm.}$) were observed in the spectra with an additional contribution due to room air in the optical path. The narrow, low pressure H₂O features were located on top of the broader, pressure-broadened contributions. For the most part, the pressure-broadened features were not a hinderance in the spectral analysis.

For the 7 μm region, the infrared radiation from a globar source was collected onto a helium-cooled arsenic-doped silicon detector whereas a quartz-iodine projection lamp was used in conjunction with a liquid N₂-cooled InSb detector for the 3.7 μm region. Each FTS run consisted of at least eight co-added interferograms with the run representing a path length of 433m in Table 1 was the result of 48 co-added interferograms. The

composite interferograms were transformed into spectral data at the Kitt Peak facility and then were transferred, by computer, to JPL.

3. MEASUREMENTS OF THE SPECTRA

The spectra were analyzed using a Sun computer work station. The computer software included two programs: one labeled LINEFINDER, and the other labeled NLLS. The first is basically a utility tool which finds line positions and relative strengths from the spectra and the second uses the technique of non-linear least-squares in which absorption line positions, strengths, line-widths and continuum parameters are fitted simultaneously in an interactive mode. These computer algorithms have been used in several previous studies by this author including the HDO (1), D₂O (2) and H₂¹⁶O (6) investigations.

The most accurate results using the NLLS program are obtained when the input list contains an accurate representation of the observed absorptions. For the 7 μm region, the initial analysis contained many un-assigned HDO and D₂O absorptions so an input line list to the NLLS program was initially comprised of LINEFINDER results. The initial NLLS results were then edited with known H₂O, HDO, and D₂O line positions and strengths and this second list was the input list from which the final NLLS measurements were derived. The second list also contained pressure-broadened H₂O contributions and these additions to the inputted list were essential in order to obtain accurate measurements of positions and strengths of low pressure features situated near the broadened lines. The results

from each run were calibrated and corrected by reference to available $H_2^{16}O$ (6), HDO (1), D_2O (2), and CO_2 (7) calibration frequencies. The line positions and strengths obtained in this manner were weighted (in reference to peak height absorptions) and averaged. HDO and D_2O lines which exhibited peak height absorptions of 95% or greater were not included in the line strength analysis. The measured line strengths were normalized to 99.9% $HD^{16}O$ of the samples and the normalized values were used in the analysis.

The analysis of the $3.7 \mu m$ region data involved a much easier task because the optical densities were much lower than those for the other region which meant that all of the H_2O (8,9), HDO (3,5), and D_2O (10) transition locations were known and the input list to the NLLS program required no editing. Frequency calibration for the $3.7 \mu m$ region was established from a few $H_2^{16}O$ lines (8,9) observed in the spectra plus several HDO lines. Several well-measured transitions in the (020)-(010) band of $HD^{16}O$ with $J < 9$ were used to determine a preliminary set of upper state, (020), rotational levels using values of the (010) state levels given in ref. (1). These values were then used to compute rotational transitions in the (020)-(000) band using ground state levels also given in Ref. (1) and the frequency values for these transitions were included as calibration standards for the upper region.

4. ASSIGNMENTS AND ENERGY LEVELS

The majority of the observed lines assigned to the pure

rotational band of HD¹⁶O were identified from calculations of frequencies using level values given by Toth (1). The majority of the other HDO, v₂, assignments were derived from ref. (1) and computed frequencies of the "hot" bands using rotational energy level values of the (020) and (100) states given by Toth et al. (3) and those of the (010) state given in ref. (1). New assignments of the higher J and/or K_a observed transitions in the (010)-(000) and (000)-(000) bands were identified in the spectra by comparing computed and observed line positions and in some cases line strengths. Several of the energy level values included in the frequency computations were previously unknown and approximate values for these were derived from calculations.

Rotational energy levels for the (000) state of HD¹⁶O for the higher J (J>8) levels were derived from the measurements of the (000)-(000) and (010)-(000) bands. The lower energy level values (J<9) for the (000) state were found to be accurately determined in the previous study (1). Values for many of the higher levels were derived in the earlier study (1) however the present analysis includes accurately measured positions for many of the weaker transitions from which a more accurate representation of these levels can be derived. Included in the analysis were measurements of the (010)-(000) band given in ref. (1) for transitions with line strengths $\geq 10^{-3}$ cm⁻²/atm. and microwave measurements used in ref. (1) for transitions involving J≥9.

The first task was to determine energy level values for the (000) state of HD¹⁶O for J>8. The method used here is the same as

that used in refs. (1,2,6). Briefly, combination difference frequencies (CDF's) in the ground state were determined from the measurements in the (010)-(000) band and were used in conjunction with the (000)-(000) band measurements. The level values were determined by the method of adding to the CDF's and the pure rotational frequencies the determined values of the lower rotational level. These results were weighted and averaged with the highest weight given to values derived from microwave measurements.

After the ground state term values and associated estimated uncertainties were determined, the rotational energy levels in the (010) vibrational state were derived from the (010)-(000) band measurements by the addition to each measured transition frequency, the appropriate lower-state energy level. These results were weighted and then averaged for each level. The same procedure was followed for deriving values of the levels for the (100) state using measurements in the (100)-(000) band. The (020) state levels were obtained from observed positions of the (020)-(000) and (020)-(010) bands. The earlier study (1) included enriched samples of ^{18}O and, to a lesser extent, enriched ^{17}O HDO samples and it was determined that the energy level values obtained in that work for the (000) and (010) states of HD^{17}O and HD^{18}O were of sufficient accuracy so that further analyses including measurements from the present study were not necessary.

Table 2 lists values of the rotational energy levels obtained in this study for the (000), (010), (100), and (020) states of

HD^{16}O along with associated estimated uncertainties. Values for $J < 9$ of the ground state given in ref. (1) are repeated in Table 2. All other values given in Table 2 were determined in the present study. Energy level values given with uncertainties of 0.003 cm^{-1} or greater may be in error by as much as $\pm .02 \text{ cm}^{-1}$.

5. LINE STRENGTHS

The strength, S , of a water vapor transition at frequency ν may be expressed to good approximation by

$$S = C(\nu/Q) (g/T) [1 - \exp(-\nu/kT)] \exp(-E(L)/kT) |R(L,U)|^2$$

$$\text{where } C = 8\pi^3/3hc$$

$$Q = Q_v \times Q_r$$

$$\text{and } E(L) = E_v(L) + E_r(L), \quad (2)$$

where Q is the partition function which can be expressed as the product of the vibrational, Q_v , and rotational, Q_r , partition functions, g ($g=1$ for all HDO transitions) is the degeneracy due to the nuclear spin of the lower state level, k is the Boltzmann constant, T is the temperature, $E(L)$ is the lower state energy, and $R(L,U)$ is the vibration-rotation dipole moment matrix element connecting the lower state, L , with the upper state, U .

Without considering interactions, the vibration-rotation dipole moment element, $R(L,U)$, given in eq. (2), can be expressed as,

$$\begin{aligned}
 R(L, U) &= \langle J'' K_a'' K_c'' | \langle V'' | \mu | V' \rangle | J' K_a' K_c' \rangle \\
 R(L, U) &= \sum_j u(\Delta V, j) x(\Delta V, j) \\
 x(\Delta V, j) &= \langle V'' J'' K_a'' K_c'' | A(j) | V' J' K_a' K_c' \rangle, \quad (3)
 \end{aligned}$$

where ψ is the dipole moment and the $u(\Delta V, j)$'s are the dipole moment coefficients of the vibrational transition denoted by ΔV , $A(j)$ are the transformed transition moment operators and prime and double prime denote upper and lower states, respectively. $x(\Delta V, 1)$ is the matrix element of the direction cosines in which $A(1) = \Phi_\alpha$ with $\alpha=z$ for A-type transitions and $\alpha=x$ for B-type transitions. The rotational wave-functions used in this work were symmetry-adapted wave-functions, $|JK\gamma\rangle$, which relate to asymmetric rotational wave-functions by the relation,

$$\begin{aligned}
 |VJK_a K_c\rangle &= |V\rangle \left| \sum_k C(VJK_a K_c K\gamma) JK\gamma \right\rangle, \\
 \text{for simplicity, } |VJK_a K_c\rangle &= |V\rangle |\text{ROT}(N)\rangle \\
 \text{and } N &= U \text{ or } L \\
 \text{and } \gamma &= K_a + K_c - J, \quad (4)
 \end{aligned}$$

where the $C(\)$'s are mixing coefficients of the wavefunctions and are dependent on the vibrational state.

The matrix elements used in the expansion of the dipole moment for B-type transitions are given in Table 3 and have been used in previous studies (1,2,6,8,9). The elements used in this work for A-type transitions are given in Table 4 and consist of the 8 elements (first 8 in Table 4) defined by Flaud and Camy-Peyret (11)

and used in ref. (1) plus 6 additional terms. It was determined from the least-squares fitting procedure of the line strengths of the (010)-(000) band A-type transitions of HD¹⁶O that the first eight terms did not adequately represent the experimental results. This was especially true for the weaker transitions. A more accurate representation was found by the addition of empirically determined matrix elements: j=9 through j=14 in Table 4.

The form of R(L,U) takes on a somewhat different appearance than that given in eq. (3) for the case of the interacting bands (100)-(010) and (020)-(010). This is because the wavefunctions of either the (100) or (020) state is a linear combination of additional functions due to Fermi and Coriolis-type interactions between the two states. The wavefunction of a level, JK_aK_c, of either state can be expressed by:

$$\begin{aligned}
 |V_n JK_a K_c\rangle &= |V_n\rangle |\sum_k C(V_n V_n JK_a K_c K\gamma) JK\gamma\rangle && (\text{Self}) \\
 &+ |V_m\rangle |\sum_k C(V_n V_m JK_a K_c K\gamma) JK\gamma\rangle && (\text{Fermi}) \\
 &+ |V_m\rangle |\sum_{k'} C(V_n V_m JK_a K_c K'\gamma') JK'\gamma'\rangle, && (\text{Coriolis}) \quad (5)
 \end{aligned}$$

where $\gamma \neq \gamma'$ and when K_a and K are even, the K' are odd and when K_a and K are odd, the K' are even, and $V_n \neq V_m$. For simplicity, eq. (5) can be expressed as:

$$|V_n JK_a K_c\rangle = |V_n\rangle |\text{ROT(Sf)}\rangle + |V_m\rangle |\text{ROT(F)}\rangle + |V_m\rangle |\text{ROT(C)}\rangle, \quad (6)$$

where Sf means self, F means Fermi, and C means Coriolis. R(L,U)

can therefore be expressed for any of the four "hot" bands as:

$$R(L, U) = \sum_j u(Sf, j)x(Sf, j) + \sum_j u(F, j)x(F, j) + \sum_j u(C, j')x(C, j')$$

$$R(L, U) = s^f R(L, U) + ^F R(L, U) + ^C R(L, U). \quad (7)$$

Eq. (7) also contains the following properties for all j :

(100)-(010) A-type band	$u(S, j) = u(1, j)$
	$u(F, j) = u(3, j)$
	$u(C, j) = u(4, j)$
(100)-(010) B-type band	$u(S, j) = u(2, j)$
	$u(F, j) = u(4, j)$
	$u(C, j) = u(3, j)$
(020)-(010) A-type band	$u(S, j) = u(3, j)$
	$u(F, j) = u(1, j)$
	$u(C, j) = u(2, j)$
(020)-(010) B-type band	$u(S, j) = u(4, j)$
	$u(F, j) = u(2, j)$
	$u(C, j) = u(1, j), \quad (8)$

where the vibrational transition symbols, 1, 2, 3, and 4 pertain to the (100)-(010) A-type band, (100)-(010) B-type band, (020)-(010) A-type band, and the (020)-(010) B-type band, respectively. The x 's given in eq. (7) have the following meaning:

$$\begin{aligned}
 x(Sf, j) &= \langle V'' J'' K_a'' K_c'' | A(j) | V_{sf} \rangle | \text{ROT}(Sf) \rangle \\
 x(F, j) &= \langle V'' J'' K_a'' K_c'' | A(j) | V_F \rangle | \text{ROT}(F) \rangle \\
 x(C, j) &= \langle V'' J'' K_a'' K_c'' | A(j) | V_C \rangle | \text{ROT}(C) \rangle,
 \end{aligned} \tag{9}$$

where $V_F = V_C \neq V_{sf}$ for this special case and double prime denotes the non-interacting lower state.

The determination of the wavefunction mixing coefficients, $C(V_n V_m J K_a K_c K \gamma)$, requires the solution of the orthogonal energy matrix, H :

$$H = \begin{vmatrix} H[Sf]_{nn} & H[F]_{nn} & H[C]_{nn} \\ H[F]_{mm} & H[Sf]_{mm} & 0 \\ H[C]_{mm} & 0 & H[Sf]_{mm}' \end{vmatrix} \tag{10}$$

where the null sub-matrices translates that Coriolis interactions do not occur between levels within one vibrational state. The matrix elements of the sub-matrices, given in terms of symmetry-adopted wavefunctions, can be expressed by the following:

$$H[Sf]_{nn}(w, y) = \langle V_n J K_w \gamma | H | V_n J K_y \gamma \rangle, K_w - K_y = 0, \pm 2, w=1 \text{ to } N \text{ and } y = 1 \text{ to } N. \tag{11a}$$

$$H[F]_{nn}(w, y) = \langle V_n J K_w \gamma | H | V_m J K_y \gamma \rangle, K_w - K_y = 0, \pm 2, w=1 \text{ to } N \text{ and } y = 1 \text{ to } N. \tag{11b}$$

$$H[Sf]_{mm}(w, y) = \langle V_m J K_w \gamma | H | V_m J K_y \gamma \rangle, K_w - K_y = 0, \pm 2, w=1 \text{ to } N \text{ and } y = 1 \text{ to } N. \tag{11c}$$

$$H[Sf]_{mm}'(w, y) = \langle V_m J K_w \gamma' | H | V_m J K_y \gamma' \rangle, K_w - K_y = 0, \pm 2, w=1 \text{ to } M \text{ and } y = 1 \text{ to } M. \tag{11d}$$

$$H[C]_{nn}(w, y) = \langle V_n J K_w \gamma | H | V_m J K_y \gamma' \rangle, K_w - K_y = \pm 1, w=1 \text{ to } N \text{ and } y = 1 \text{ to } M, \tag{11e}$$

where $\gamma \neq \gamma'$, $V_n \neq V_m$, and $N - M = 0, \pm 1$ and when $M=0$, no Coriolis

interactions occur. If the above requirements are not met, then the matrix element is zero. The matrix elements derived from eq.(11a) are the only ones required for the determination of the C()'s for the non-interacting bands, (000)-(000) and (010)-(000). Expressions for the matrix elements given above and used in this work are listed by Kwan (12) who included a Watson-type (13) Hamiltonian in the diagonal part of the Hamiltonian.

Vibration-rotation frequency parameters obtained in other studies were applied in the present work for the determination of the wavefunction mixing coefficients from the solution of the H-matrix displayed in eq. (10). These included the following parameter values: the parameters of the (000) from ref.(1), the (010) state from the work of Flaud et al. (14), and the (020) and (100) states from Perrin et al. (5) who solved the complete H-matrix and included Fermi and Coriolis-type parameters.

The dipole moment expansion coefficients derived from the least-squares fit of the measured line strengths using the methods described above, the energy levels given in Table 2, and the matrix elements given in Tables 3 and 4 are listed in Table 5. The number of lines fitted, N, and given below the dipole moment coefficients in Table 5 are not all of the lines measured. The strengths of the lines included in each analysis were measured to good accuracy with estimated uncertainties of 6% or less. The standard deviation in percent, $\sigma\%$, given below each set of results were derived from the expression:

$$\sigma\% = \{\sum [(S_{\text{obs}} - S_{\text{cal}})/S_{\text{obs}}]^2/N\}^{1/2} \times 100. \quad (12)$$

Inspection of the table shows that the results for the (010)-(000) bands (B-type and A-type) are given in terms of sets with each set representing a frequency interval. The same was also found in my recent work on the (010)-(000) band of H₂¹⁶O (6) in which the theory in the present state is not adequate to take care of all the necessary measurements in one fitting procedure. However one fit was adequate in the analysis of the line strengths measured in my earlier HDO study (1) because the theory can account for all of the stronger transitions. The addition of the weaker transitions in the present study made the above requirement (separating the measurements into sets) necessary.

It was not necessary to separate the data into frequency intervals for fitting the "hot" bands because the range of line strength values were within the range (all strength values within about 3 to 4 orders of magnitude of each other) for the theory to operate sufficiently well with all measurements included in one fitting procedure. However other problems existed in the fitting process which involved relative signs of the transition moment constants, u(n,j), and localized strong Coriolis-type interactions. Comparisons of the experimental line strength results with computed values (using any of the sign conventions for the dipole moment terms) from the theory used in this study show that the wavefunction mixing coefficients are predicted to be too small in magnitude for a few levels affected by strong Coriolis

perturbations. Analysis of the data show that the correct relative dipole sign set is determined mainly from an accurate knowledge of the mixing coefficients for these levels of the (100) state. The majority of the strength of any transition in the (100)-(010) band is "borrowed" from the (020)-(010) band in which the contributing factors are mainly Fermi-type interactions for the majority of the transitions and Coriolis-type interactions for the few transitions affected by strong, localized perturbations. Perrin et al. (5) noted that to do the theory properly for HDO, one has to perform up to second order of perturbation and a first order rotational contact transformation which they did not do in their analysis of the (020)-(000) and (100)-(000) bands. Instead, they included specific resonant operators in the Hamiltonian which only affected the 6 4 2 level of the (100) state and the 6 3 4 level of the (020) state. The values they (5) obtained for the coefficients of these levels were applied in the present study, which in turn, was the aid necessary to determine the correct relative sign set. The relative signs of the leading dipole moment term, $u(\Delta V, 1)$, for the B-type (020)-(010) band, A-type (020)-(010) band, B-type (100)-(010) band and the A-type (100)-(010) band were found to be -+++, respectively, and this is the set given in Table 5 for these bands. Further analysis of the data showed that the wavefunction mixing coefficients of a few additional levels required improvements over the theoretical predictions due to Coriolis interactions. Values for these coefficients as well as those for the levels improved by Perrin et al. (5) and given above were derived from a comparison

between experimental and computed strengths in a two step iterative process. The values for the major coefficients of these levels are listed in Table 6. The table lists the rotational level, experimentally determined value of the coefficient, the difference between the observed level frequency (given in Table 2) and computed value, Δ , and the difference between the observed level frequencies of the interacting levels, δ . Table 6 is given with the interacting levels on the same row. δ given in Table 6 is E(020)-E(100) with the sign for the (020) state coefficients equal to the sign of δ . The magnitude of the value derived in this study for the 6 3 4 level of the (020) state equals that of the 6 4 2 level of the (100) state and close to the value found by Perrin et al. (5); 0.434. It is interesting to note that the magnitudes of Δ are proportional to those of the mixing coefficients as exemplified in Table 6 which relates to the inadequacy of the theory used here for the strong interacting levels.

6. RESULTS

Table 7 is a listing of the measurements for the pure-rotational band from 657 to 1030 cm^{-1} . The table gives the observed line positions, the observed minus computed line positions, o-c, the rotational quantum assignments, lower state energy, observed strength, estimated uncertainty in the observed strength, %s, calculated strength and observed minus computed strength, (o-c)%. Lines labeled with an asterisk, *, before the frequency are doubled absorptions which were not adequately resolved in the spectra. The

entries for these lines include one of the two quantum assignments and the sum of the strengths of the two comparable transitions. The computed positions were derived from the energy levels given in Table 2 and the computed strengths were calculated from eqs. (2,3) and the dipole matrix elements given in Table 5. It is interesting to note that the lines measured in this work for the (000)-(000) band are located far from the origin ($0. \text{ cm}^{-1}$) and the dipole elements derived from the present data set may not resemble those derived from data near the origin yet the leading dipole element obtained in this work of $1.78(8)$ Debyes is close to the value for the permanent dipole-moment of HDO of 1.84 D (15). Only six A-type transitions were measured. They were all very weak ($S < 3.0 \times 10^{-5} \text{ cm}^{-2}/\text{atm.}$) and they were not analyzed in this study.

The listing for the (010)-(000) bands of HD^{16}O contains over 1700 lines (several of which are doubled lines) and the complete listing is not given in this report however many of them will be presented in a paper discussing linewidth measurements. One interesting finding was that several far R-branch $\Delta K_a = 2$ A-type transitions required that their respective f-factors must be negative in order to obtain a good fit of the line strengths. The f-factor has been defined in previous studies (1,2,6) in which the expression given in eq. (2) can be given in another fashion after factoring out the matrix element of the direction cosine $x(\Delta V, 1) = l :$

$$S = (v/v_o) S_v l^2 f^2 g [1 - \exp(v/kT)] \exp(-E_R(L)/kT) / Q_R$$

where $S_v = 8\pi^3 |u(\Delta V, 1)|^2 v_o \exp(-E_v(L)/kT) / (3hckTQ_v)$ (13)

where S_v is the vibrational band strength and v_0 is the band center frequency. f measures the degree of non-rigidity of the strength and $f=1$ for rigid-rotor transitions. The method used in this work for fitting the line strengths was to fit the square-root of the strength and assume that the sign of the value was the same sign as ℓ . Inspection of eq.(13) shows that the sign of \sqrt{S} follows the result of the product of the respective signs of ℓ times f where for most cases, f is positive but, as noted above, negative for many of the far R-branch, $\Delta K_a = 2$ transitions of the (010)-(000) band and this condition was also found for several far-R branch transitions of the (010)-(000) band of $H_2^{16}O$ (6). Table 8 shows the portion of the (010)-(000) A-type band where this phenomena occurs in the data. The table is given in a similar form to that of Table 7 with the addition of values for ℓ and f . The listing shows the lowest frequency transitions with $\Delta K_a = 2$ with positive f whereas the higher frequency lines with $\Delta K_a = 2$ exhibit negative f values. In this region one can picture the $\Delta K_a = 2$ transition strengths passing through a minimum (from positive f to negative f) following a form similar to that for perpendicular bands of triatomic molecules where f can be expressed as $f = (1 - \delta m)$ where m is positive for R-branch lines and negative for P-branch transitions and δ is a constant.

The fit of the B-type transitions of the (010)-(000) band did not include negative f values although negative f values were derived for far R-branch transitions of the (010)-(000) band of $H_2^{16}O$ (6) in a region farther from the band center than observed in

the present work for the HDO band. This would indicate that the change of sign for f from positive to negative happens nearer the band center for A-type bands than B-type bands for water type molecules.

The line strength, S , of a given transition for the interacting bands, $(020)-(010)$ and $(100)-(010)$, can be expressed in a form following from eqs. (2 and 7) as:

where S_f , F , and C pertains to self, Fermi, and Coriolis, respectively and " $R(L,U)$ " is the dipole moment matrix element due to the interaction n . $S(n)$ is a computed strength due to the interaction, n , and if $S(F)$ and $S(C)$ are both zero, then there are no interactions and eq. (14) reduces to eq. (2).

Table 9 is a listing of measurements obtained for the B-type (020)-(010) band given in a similar form to that of table 7. Table 9 also includes the values of Z1, Z2, and Z3 as defined in eq. (14) and these entries are given in the last three columns of the table. The letters PR given before the line position value denotes a strong Coriolis interaction due to a level in the (100) state. The upper state quantum assignments of transitions labeled with PR are listed in Table 6. The computed positions were derived from the energy levels given in table 2 and the computed strengths

were derived from the dipole moment coefficients given in Table 5 and eqs. (2,7) where the various contributions to the computed strength are given in the last three columns.

Tables 10-12 are similar listings for the A-type (020)-(010) band, the B-type (100)-(010) band and the A-type (100)-(010) band, respectively. Inspection of Tables 11 and 12 shows that the Fermi contributions, Z₂, are greater in magnitude than those of self (Z₁) and Coriolis (Z₃) for lines not labeled with a PR. Lines labeled with PR show that the (020)-(010) band contributions are even greater due to the large Coriolis addition, Z₃.

6. CONCLUSION

Several thousand lines of HDO and D₂O were measured at high optical densities and low sample pressures. This study involved HD¹⁶O transitions from which an analysis of the measured line strengths for the (000)-(000) (high frequency), (010)-(000), (020)-(010), and (100)-(010) bands produced accurate values for the respective dipole moment expansion coefficients. The A-type dipole moment expansion included additional terms ($j=9$ through 14) to adequately fit the A-type (010)-(000) line strengths. It was also found that the f-factor ($f^2=F$) used in the line strength expression changes sign for positive to negative in the region of the far R-branch $\Delta K_a=2$ transitions for this band.

Eighty six lines of the pure rotational band were measured of which 80 were B-type transitions. The line strength analysis of the B-type band resulted in the leading dipole moment expansion

term ($j=1$) equal to $1.78(8)$ D which is close to the value of the permanent dipole moment for HDO (1.84 D).

589 lines of the "hot" bands, (020)-(010) and (100)-(010), were measured and the line strength analysis included perturbation techniques which took into account Fermi and Coriolis-type interactions. Localized, strong Coriolis interactions affected a few of the transition strengths in a manner in which the theory underestimated the magnitude of the interactions. Therefore empirical coefficients replaced theoretical values for the affected transitions. After these modifications, it was possible to reproduce the experimental line strengths for the interacting bands.

7. ACKNOWLEDGEMENTS

The author wishes to thank the Kitt Peak National Observatory for the use of the FTS and C. Plymate for assistance in obtaining the HDO/D₂O spectra. The research described in this paper was performed at the Jet Propulsion Laboratory, California Institute of Technology, under contract with The National Aeronautics and Space Administration.

REFERENCES

1. R. A. Toth, J. Mol. Spectrosc. 162, 20-40 (1993).
2. R. A. Toth, J. Mol. Spectrosc. 162, 41-54 (1993).
3. Toth, R. A., Gupta, V. D. & Brault, W.,
4. N. Papineau, C. Camy-Peyret, J.-M. Flaud, and G. Guelachvili, J. Mol. Spectrosc. 92, 451-468 (1982).
5. A. Perrin, J.-M. Flaud, and C. Camy-Peyret, J. Mol. Spectrosc. 112, 153-162 (1985).
6. R. A. Toth, J. Mol. Spectrosc. 190, 379-396 (1998).
7. L. S. Rothman, R. R. Gamache, R. H. Tipping C. P. Rinsland, M. A. H. Smith, D. C. Benner, V. M. Devi, J.-M. Flaud, C. Camy-Peyret, A. Perrin, A. Goldman, S. T. Massie, L. R. Brown, and R. A. Toth, "The HITRAN molecular database: editions of 1991 and 1992," J. Quant. Spectrosc. Rad. Transfer 48, 469-507(1993).
8. R. A. Toth, J. Opt. Soc. Am. B 10, 1526-1544 (1993).
9. R. A. Toth, J. Opt. Soc. Am. 10, 2006-2029 (1993).
10. N. Papineau, J.-M. Flaud, C. Camy-Peyret, and G. Guelachvili, J. Mol. Spectrosc. 87, 219-232 (1981).
11. J.-M. Flaud and C. Camy-Peyret, J. Mol. Spectrosc. 55, 278-310 (1975).
12. Y. Y. Kwan, J. Mol. Spectrosc. 71, 260-280 (1978).
13. J. K. G. Watson, J. Chem. Phys. 46, 1935-1949 (1967).
14. J.-M. Flaud, C. Camy-Peyret, A. Mahmoudi, and G. Guelachvili, International J. of Infrared and Millimeter Waves 7, 1063-1090 (1986).

15. C. H. Townes and A. L. Schawlow, "Microwave Spectroscopy",
McGraw-Hill book Co. see page 639 (1955).

Table 1. Experimental conditions of water vapor samples.
All samples at or near room temperature (296K).

frequency interval	res. (cm ⁻¹)	pres. (Torr)	path (m)	percent abundance of isotopic species		
				D ₂ O	HDO	H ₂ O
500-2200	0.0054	1.19	25	50.6	40.0	9.4
500-2200	0.0054	0.78	73	47.0	42.3	10.7
500-2200	0.0054	1.30	25	41.3	44.6	14.1
500-2200	0.0054	1.24	73	39.7	45.6	14.7
500-2200	0.0054	1.22	433	38.7	46.2	15.1
500-2200	0.0054	1.21	193	37.4	46.7	15.9
2000-4500	0.011	1.73	2.39	59.3	36.1	4.6
2000-4500	0.011	0.99	2.39	21.9	46.9	31.2
2000-4500	0.011	5.14	2.39	14.6	44.7	40.7
2000-4500	0.011	0.51	2.39	30.6	47.2	22.2
2000-4500	0.011	1.48	2.39	40.8	46.5	12.7

frequency intervals in cm⁻¹ and represent the spectral coverage
of the data.

Table 2. Rotational energy levels (cm^{-1}) of the (000), (010), (100), and (020) vibrational states of HD^{16}O

J	K_a	k_c	(000)	(010)	(100)	(020)	J	K_a	k_c
0	0	0	0.0	1403.48372(1.)	2723.67980(40.)	2782.01112(3.)	0	0	0
1	0	1	15.508207(0.5)	1419.04120(3.)	2738.91581(20.)	2797.60922(2.)	1	0	1
1	1	1	29.808573(0.5)	1435.30007(3.)	2753.32772(4.)	2816.21351(4.)	1	1	1
1	1	0	32.496372(0.5)	1438.19995(2.)	2755.96594(4.)	2819.29062(2.)	1	1	0
2	0	2	46.173113(0.5)	1449.79413(3.)	2769.04990(6.)	2828.44471(3.)	2	0	2
2	1	2	58.126885(0.5)	1463.50514(1.)	2781.14652(18.)	2844.32733(4.)	2	1	2
2	1	1	66.184507(0.5)	1472.19763(2.)	2789.05427(3.)	2853.55179(5.)	2	1	1
2	2	1	108.926236(0.5)	1520.69008(3.)	2831.92955(4.)	2909.05107(8.)	2	2	1
2	2	0	109.269080(0.5)	1521.04224(3.)	2832.25976(4.)	2909.39956(6.)	2	2	0
3	0	3	91.330235(0.5)	1495.05540(5.)	2813.44206(3.)	2873.83253(7.)	3	0	3
3	1	3	100.390895(0.5)	1505.59304(3.)	2822.66958(8.)	2886.27986(5.)	3	1	3
3	1	2	116.461334(0.5)	1522.93002(2.)	2838.43913(8.)	2904.68209(3.)	3	1	2
3	2	2	155.388996(0.5)	1567.30043(2.)	2877.55360(14.)	2955.80631(5.)	3	2	2
3	2	1	157.064705(0.5)	1569.02412(2.)	2879.16570(5.)	2957.51416(3.)	3	2	1
3	3	1	233.023722(0.5)	1654.65853(2.)	2954.92638(10.)	3054.93338(4.)	3	3	1
3	3	0	233.051229(0.5)	1654.68539(2.)	2954.95060(5.)	3054.95848(10.)	3	3	0
4	0	4	150.156237(0.5)	1553.96140(3.)	2871.29312(20.)	2932.90009(5.)	4	0	4
4	1	4	156.382233(0.5)	1561.33786(3.)	2877.68712(5.)	2941.83457(4.)	4	1	4
4	1	3	182.983536(0.5)	1590.04499(3.)	2903.79005(15.)	2972.33524(8.)	4	1	3
4	2	3	217.041901(0.5)	1629.14174(3.)	2938.10103(10.)	3017.84100(5.)	4	2	3
4	2	2	221.836125(0.5)	1634.08873(3.)	2942.72072(5.)	3022.76595(5.)	4	2	2
4	3	2	295.48727(2.)	1717.33552(2.)	3016.22896(9.)	3117.81018(5.)	4	3	2
4	3	1	295.67750(2.)	1717.52139(3.)	3016.40414(15.)	3117.98155(5.)	4	3	1
4	4	1	402.32915(2.)	1837.01632(8.)	3122.45815(10.)	3253.00518(8.)	4	4	1
4	4	0	402.33098(3.)	1837.01803(5.)	3122.46025(20.)	3253.00624(18.)	4	4	0
5	0	5	221.94609(2.)	1625.74795(2.)	2941.90710(6.)	3004.83592(7.)	5	0	5
5	1	5	225.864852(0.5)	1630.49320(2.)	2945.97055(10.)	3010.76694(6.)	5	1	5
5	1	4	265.23622(2.)	1673.01753(2.)	2984.61272(4.)	3055.99855(7.)	5	1	4
5	2	4	293.63653(1.)	1705.95890(3.)	3013.33384(5.)	3094.90645(10.)	5	2	4
5	2	3	303.99483(2.)	1716.69586(3.)	3023.30888(4.)	3105.66415(10.)	5	2	3
5	3	3	373.66590(3.)	1795.78811(4.)	3092.95575(5.)	3196.51493(15.)	5	3	3
5	3	2	374.40999(3.)	1796.51591(3.)	3093.64545(4.)	3197.18605(8.)	5	3	2
5	4	2	480.24267(2.)	1915.18769(4.)	3198.90274(9.)	3331.42820(5.)	5	4	2
5	4	1	480.25889(3.)	1915.20279(4.)	3198.91689(8.)	3331.44126(9.)	5	4	1
5	5	1	615.96876(4.)	2066.30403(5.)	3333.70990(20.)	3500.86720(30.)	5	5	1
5	5	0	615.96879(4.)	2066.30407(4.)	3333.71030(20.)	3500.86780(30.)	5	5	0
6	0	6	306.31477(2.)	1709.97129(2.)	3024.89262(5.)	3089.12553(7.)	6	0	6
6	1	6	308.61570(1.)	1712.82379(3.)	3027.30242(6.)	3092.81070(4.)	6	1	6
6	1	5	362.50715(3.)	1771.12334(4.)	3080.22465(8.)	3154.96484(4.)	6	1	5
6	2	5	384.87556(2.)	1797.44628(4.)	3102.96672(4.)	3186.62612(4.)	6	2	5
6	2	4	403.54901(3.)	1816.90104(3.)	3120.98336(28.)	3206.33595(10.)	6	2	4
6	3	4	467.51457(1.)	1889.97638(2.)	3185.06714(5.)	3291.07170(7.)	6	3	4
6	3	3	469.66363(2.)	1892.08299(3.)	3187.14189(7.)	3292.97603(7.)	6	3	3
6	4	3	573.89076(4.)	2009.14654(3.)	3290.77300(16.)	3425.68500(10.)	6	4	3
6	4	2	573.97061(3.)	2009.22088(4.)	3290.80008(10.)	3425.74880(20.)	6	4	2
6	5	2	709.16662(2.)	2159.80113(4.)	3425.12119(40.)	3594.66850(30.)	6	5	2
6	5	1	709.16781(3.)	2159.80220(4.)	3425.12167(40.)	3594.66850(20.)	6	5	1
6	6	1	872.79052(4.)	2340.77270(3.)	3587.63630(30.)	3795.87985(25.)	6	6	1
6	6	0	872.79052(4.)	2340.77270(3.)	3587.63630(30.)	3795.87985(25.)	6	6	0
7	0	7	403.16148(3.)	1806.49638(2.)	3120.13821(19.)	3185.57910(10.)	7	0	7
7	1	7	404.44564(2.)	1808.12761(3.)	3121.49700(5.)	3187.75957(10.)	7	1	7
7	1	6	473.91767(3.)	1883.46104(3.)	3189.77974(8.)	3268.34543(6.)	7	1	6
7	2	6	490.42738(3.)	1903.26203(4.)	3206.68038(12.)	3292.82929(4.)	7	2	6
7	2	5	520.12352(3.)	1934.35255(4.)	3235.39022(15.)	3324.49043(4.)	7	2	5
7	3	5	576.90473(2.)	1999.77680(4.)	3292.44421(10.)	3401.21790(6.)	7	3	5
7	3	4	581.96208(3.)	2004.75458(3.)	3297.22552(10.)	3405.84757(7.)	7	3	4
7	4	4	683.32398(3.)	2118.94522(5.)	3398.13857(5.)	3535.81765(4.)	7	4	4
7	4	3	683.61010(3.)	2119.21143(4.)	3398.39640(8.)	3536.04660(10.)	7	4	3
7	5	3	818.00667(4.)	2268.98739(6.)	3531.87630(10.)	3704.19548(25.)	7	5	3
7	5	2	818.01365(4.)	2268.99357(4.)	3531.88230(25.)	3704.20080(25.)	7	5	2
7	6	2	981.12801(6.)	2449.44417(8.)	3693.86720(20.)	3904.89898(25.)	7	6	2
7	6	1	981.12805(6.)	2449.44423(8.)	3693.86720(20.)	3904.89898(25.)	7	6	1
7	7	1	1171.53163(5.)	2658.60700(7.)	3883.07509(10.)	4135.47769(40.)	7	7	1
7	7	0	1171.53163(5.)	2658.60700(7.)	3883.07509(10.)	4135.47769(40.)	7	7	0
8	0	8	512.51582(3.)	1915.34502(3.)	3227.66911(4.)	3294.19670(7.)	8	0	8
8	1	8	513.20719(2.)	1916.24549(3.)	3228.40777(10.)	3295.44298(20.)	8	1	8
8	1	7	598.56311(3.)	2009.07698(3.)	3312.39530(70.)	3395.16820(8.)	8	1	7
8	2	7	609.94656(3.)	2023.04816(2.)	3324.14105(15.)	3413.01229(5.)	8	2	7
8	2	6	653.08875(4.)	2068.42163(5.)	3365.93198(15.)	3459.53418(3.)	8	2	6
8	3	6	701.62044(3.)	2124.97673(5.)	3414.88412(20.)	3526.89350(8.)	8	3	6
8	3	5	711.79542(4.)	2135.05500(5.)	3424.51952(10.)	3536.35427(6.)	8	3	5
8	4	5	808.56317(3.)	2244.60802(4.)	3521.01178(5.)	3661.85950(20.)	8	4	5
8	4	4	809.39325(3.)	2245.38085(4.)	3521.77115(10.)	3662.52512(15.)	8	4	4
8	5	4	942.53244(5.)	2393.90460(4.)	3654.01445(8.)	3829.48597(20.)	8	5	4
8	5	3	942.56218(5.)	2393.93097(6.)	3654.04100(5.)	3829.50750(20.)	8	5	3

Table 2 continued

J	K _a	k _c	(000)	(010)	(100)	(020)	J	K _a	k _c
8	6	3	1105.00339(5.)	2573.69587(8.)	3815.33378(90.)	4029.53270(60.)	8	6	3
8	6	2	1105.00391(5.)	2573.69634(5.)	3815.33400(40.)	4029.53300(60.)	8	6	2
8	7	2	1294.83641(5.)	2782.27037(8.)	4003.94234(35.)	4259.51940(60.)	8	7	2
8	7	1	1294.83641(5.)	2782.27037(8.)	4003.94234(35.)	4259.51940(60.)	8	7	1
8	8	1	1510.87830(8.)	3018.01272(6.)	4218.80533(40.)	4517.27400(300.)	8	8	1
8	8	0	1510.87830(8.)	3018.01272(6.)	4218.80533(40.)	4517.27400(300.)	8	8	0
9	0	9	634.42821(4.)	2036.57363(3.)	3347.53435(15.)	3415.03600(5.)	9	0	9
9	1	9	634.79092(4.)	2037.05853(3.)	3347.92562(5.)	3415.73146(10.)	9	1	9
9	1	8	735.73515(3.)	2147.18202(4.)	3447.36240(20.)	3534.56996(17.)	9	1	8
9	2	8	743.09739(3.)	2156.45406(4.)	3455.02239(8.)	3546.85293(15.)	9	2	8
9	2	7	801.64407(2.)	2218.29868(4.)	3511.84250(4.)	3610.68140(20.)	9	2	7
9	3	7	841.36760(3.)	2265.28283(5.)	3552.10822(8.)	3667.77640(20.)	9	3	7
9	3	6	859.39255(3.)	2283.28039(5.)	3569.23213(5.)	3684.86795(10.)	9	3	6
9	4	6	949.57739(5.)	2386.10979(3.)	3659.36985(12.)	3803.79026(15.)	9	4	6
9	4	5	951.63565(4.)	2388.02981(8.)	3661.26351(35.)	3805.44935(25.)	9	4	5
9	5	5	1082.78507(3.)	2534.59183(5.)	3791.57743(5.)	3970.57272(100.)	9	5	5
9	5	4	1082.88663(3.)	2534.68185(3.)	3791.66805(65.)	3970.64504(25.)	9	5	4
9	6	4	1244.43726(3.)	2713.54502(9.)	3952.05718(40.)	4169.79134(30.)	9	6	4
9	6	3	1244.43990(3.)	2713.54723(6.)	3952.06024(40.)	4169.79181(30.)	9	6	3
9	7	3	1433.57220(10.)	2921.40200(8.)	4139.93690(50.)	4399.06150(80.)	9	7	3
9	7	2	1433.57225(20.)	2921.40200(8.)	4139.93690(50.)	4399.06150(80.)	9	7	2
9	8	2	1648.94742(5.)	3156.45035(9.)	4354.09400(70.)		9	8	2
9	8	1	1648.94742(5.)	3156.45035(9.)	4354.09400(70.)		9	8	1
9	9	1	1889.50750(10.)	3417.26620(15.)	4593.57765(300.)		9	9	1
9	9	0	1889.50750(10.)	3417.26620(15.)	4593.57765(300.)		9	9	0
10	0	10	768.93004(4.)	2170.22362(2.)	3479.76654(40.)	3548.14803(15.)	10	0	10
10	1	10	769.11689(4.)	2170.48018(2.)	3479.97015(8.)	3548.52970(40.)	10	1	10
10	1	9	885.06459(4.)	2297.32081(2.)	3594.29580(30.)	3685.98175(15.)	10	1	9
10	2	9	889.57588(5.)	2303.15867(2.)	3599.02656(16.)	3694.01953(25.)	10	2	9
10	2	8	964.85063(5.)	2383.03280(6.)	3672.22079(5.)	3777.00293(15.)	10	2	8
10	3	8	995.79344(3.)	2420.33891(8.)	3703.77948(15.)	3823.52268(15.)	10	3	8
10	3	7	1024.56859(4.)	2449.32149(7.)	3731.21568(50.)	3851.39844(20.)	10	3	7
10	4	7	1106.26431(4.)	2543.35611(4.)	3813.12023(10.)	3961.52840(25.)	10	4	7
10	4	6	1110.75978(3.)	2547.56553(5.)	3817.27495(15.)	3965.18310(25.)	10	4	6
10	5	6	1238.79446(3.)	2691.07775(5.)	3944.59662(60.)	4127.47820(100.)	10	5	6
10	5	5	1239.08924(3.)	2691.33884(6.)	3944.86236(35.)	4127.68820(20.)	10	5	5
10	6	5	1399.45041(3.)	2869.00831(5.)	4104.05861(20.)	4325.68264(50.)	10	6	5
10	6	4	1399.46074(5.)	2869.01712(3.)	4104.06830(15.)	4325.68560(50.)	10	6	4
10	7	4	1587.74024(6.)	3075.99944(10.)	4291.06121(50.)		10	7	4
10	7	3	1587.74047(6.)	3075.99975(20.)	4291.06121(50.)		10	7	3
10	8	3	1802.33533(8.)	3310.23936(5.)	4504.39565(20.)		10	8	3
10	8	2	1802.33533(8.)	3310.23936(5.)	4504.39565(20.)		10	8	2
10	9	2	2042.10520(20.)	3570.22533(12.)	4743.04520(300.)		10	9	2
10	9	1	2042.10520(20.)	3570.22533(12.)	4743.04520(300.)		10	9	1
10	10	1	2306.11250(25.)	3854.74123(50.)			10	10	1
10	10	0	2306.11250(25.)	3854.74123(50.)			10	10	0
11	0	11	916.02906(3.)	2316.31176(5.)	3624.37574(5.)	3693.56039(20.)	11	0	11
11	1	11	916.12401(2.)	2316.44577(3.)	3624.48016(7.)	3693.76741(8.)	11	1	11
11	1	10	1046.47441(3.)	2459.36080(6.)	3753.09954(10.)	3849.17162(20.)	11	1	10
11	2	10	1049.12452(2.)	2462.88698(4.)	3755.89880(10.)	3854.22140(30.)	11	2	10
11	2	9	1141.69174(3.)	2561.58019(4.)	3846.08340(30.)	3957.46422(10.)	11	2	9
11	3	9	1164.50992(4.)	2589.74985(7.)	3869.52455(20.)	3993.75597(8.)	11	3	9
11	3	8	1206.75477(4.)	2632.66004(11.)	3909.94966(30.)	4035.53778(10.)	11	3	8
11	4	8	1278.43842(5.)	2716.17024(4.)	3982.09327(20.)	4134.91452(40.)	11	4	8
11	4	7	1287.23874(7.)	2724.46268(4.)	3990.24950(5.)	4142.17260(50.)	11	4	7
11	5	7	1410.56674(5.)	2863.36860(5.)	4113.08320(30.)		11	5	7
11	5	6	1411.32008(10.)	2864.03581(3.)	4113.76204(15.)		11	5	6
11	6	6	1570.06188(6.)	3040.10011(9.)	4271.35711(40.)		11	6	6
11	6	5	1570.09609(6.)	3040.12905(7.)	4271.38724(40.)		11	6	5
11	7	5	1757.34117(5.)	3246.05836(5.)	4457.31670(100.)		11	7	5
11	7	4	1757.34214(6.)	3246.05910(20.)	4457.31722(10.)		11	7	4
11	8	4	1971.03034(5.)	3479.36323(20.)	4669.68300(300.)		11	8	4
11	8	3	1971.03034(5.)	3479.36323(20.)	4669.68300(300.)		11	8	3
11	9	3	2209.90582(10.)	3738.41337(7.)			11	9	3
11	9	2	2209.90582(10.)	3738.41337(7.)			11	9	2
11	10	2	2472.97420(10.)				11	10	2
11	10	1	2472.97420(10.)				11	10	1
12	0	12	1075.71474(3.)	2474.83461(4.)	3781.35240(5.)	3851.27920(20.)	12	0	12
12	1	12	1075.76247(3.)	2474.90410(3.)	3781.40645(40.)	3851.39076(20.)	12	1	12
12	1	11	1220.02912(5.)	2633.35231(6.)	3923.83174(10.)	4024.14216(20.)	12	1	11
12	2	11	1221.53740(4.)	2635.41688(7.)	3925.43485(10.)	4027.21833(25.)	12	2	11
12	2	10	1331.21696(8.)	2752.92597(5.)	4032.49454(40.)	4151.01671(60.)	12	2	10
12	3	10	1347.12021(7.)	2773.10670(3.)	4048.95910(55.)	4177.91204(20.)	12	3	10
12	3	9	1405.12565(7.)	2832.49026(7.)	4104.65300(300.)	4236.55225(15.)	12	3	9
12	4	9	1465.82976(3.)	2904.29089(9.)	4166.03532(40.)		12	4	9
12	4	8	1481.44392(10.)	2919.13593(3.)	4180.72102(40.)		12	4	8

Table 2 continued

J	K _a	k _c	(000)	(010)	(100)	(020)	J	K _a	k _c
12	5	8	1598.06844(5.)	3051.43325(6.)	4297.00710(40.)		12	5	8
12	5	7	1599.80023(5.)	3052.96937(13.)	4298.57766(30.)		12	5	7
12	6	7	1756.28573(6.)	3226.82861(7.)	4453.96990(150.)		12	6	7
12	6	6	1756.38490(5.)	3226.91253(6.)	4454.05618(300.)		12	6	6
12	7	6	1942.37256(7.)	3431.57118(20.)	4638.70617(300.)		12	7	6
12	7	5	1942.37605(8.)	3431.57350(25.)	4638.70617(300.)		12	7	5
12	8	5	2155.01697(10.)	3663.80148(25.)			12	8	5
12	8	4	2155.01697(10.)	3663.80148(25.)			12	8	4
12	9	4	2392.88585(10.)	3921.80369(20.)			12	9	4
12	9	3	2392.88585(10.)	3921.80369(20.)			12	9	3
12	10	3	2655.08496(60.)				12	10	3
12	10	2	2655.08496(60.)				12	10	2
13	0	13	1247.96434(6.)	2645.77504(4.)	3950.67350(20.)	4021.29460(40.)	13	0	13
13	1	13	1247.98827(4.)	2645.81083(3.)	3950.70464(40.)	4021.35396(40.)	13	1	13
13	1	12	1405.81844(7.)	2819.39583(4.)	4106.58066(40.)	4210.99110(20.)	13	1	12
13	2	12	1406.65679(7.)	2820.57728(4.)	4107.47590(60.)	4212.82410(50.)	13	2	12
13	2	11	1532.73216(3.)	2956.26769(6.)	4230.74496(300.)	4356.75475(40.)	13	2	11
13	3	11	1543.24408(7.)	2970.01315(10.)	4241.71141(40.)	4375.88121(60.)	13	3	11
13	3	10	1618.70073(9.)	3047.83202(7.)	4314.39115(40.)		13	3	10
13	4	10	1668.09633(6.)	3107.38111(9.)	4364.62176(300.)		13	4	10
13	4	9	1693.44335(8.)	3131.74546(7.)	4388.48207(40.)		13	4	9
13	5	9	1801.20750(10.)	3255.18728(7.)	4496.29045(300.)		13	5	9
13	5	8	1804.84019(11.)	3258.41845(9.)			13	5	8
13	6	8	1958.12509(6.)	3429.19196(10.)			13	6	8
13	6	7	1958.38311(7.)	3429.40984(15.)			13	6	7
13	7	7	2142.82922(8.)	3632.52430(25.)			13	7	7
13	7	6	2142.84056(10.)	3632.53312(25.)			13	7	6
13	8	6	2354.27587(10.)	3863.52915(15.)			13	8	6
13	8	5	2354.27622(10.)	3863.52915(15.)			13	8	5
13	9	5	2591.01835(15.)				13	9	5
13	9	4	2591.01835(15.)				13	9	4
13	10	4	2851.90757(300.)				13	10	4
13	10	3	2851.90757(300.)				13	10	3
14	0	14	1432.74664(4.)	2829.10653(3.)	4132.31454(40.)	4203.58627(200.)	14	0	14
14	1	14	1432.75840(2.)	2829.12490(25.)	4132.32737(40.)	4203.61500(100.)	14	1	14
14	1	13	1603.90583(7.)	3017.57470(12.)	4301.41059(30.)	4409.82190(80.)	14	1	13
14	2	13	1604.36370(4.)	3018.23975(5.)	4301.90220(30.)	4410.89618(20.)	14	2	13
14	2	12	1745.89694(8.)	3171.14804(9.)	4440.46900(300.)		14	2	12
14	3	12	1752.53784(9.)	3180.10646(8.)	4447.45400(300.)		14	3	12
14	3	11	1846.40256(10.)	3277.60118(8.)	4538.12977(40.)		14	3	11
14	4	11	1884.84266(10.)	3325.04690(15.)			14	4	11
14	4	10	1922.88839(9.)	3362.05273(12.)			14	4	10
14	5	10	2019.82300(9.)	3474.47800(10.)			14	5	10
14	5	9	2026.83215(20.)	3480.74550(25.)			14	5	9
14	6	9	2175.56425(15.)	3647.16966(15.)			14	6	9
14	6	8	2176.17770(15.)	3647.68685(60.)			14	6	8
14	7	8	2358.70145(10.)	3848.89998(15.)			14	7	8
14	7	7	2358.73365(10.)	3848.92625(10.)			14	7	7
14	8	7	2568.78276(10.)				14	8	7
14	8	6	2568.78367(10.)				14	8	6
14	9	6	2804.27106(25.)				14	9	6
14	9	5	2804.27106(25.)				14	9	5
14	10	5	3063.91231(25.)				14	10	5
14	10	4	3063.91231(25.)				14	10	4
15	0	15	1630.02276(11.)	3024.79565(30.)	4326.25000(300.)	4398.13000(300.)	15	0	15
15	1	15	1630.02800(40.)	3024.80530(15.)	4326.25800(300.)	4398.14400(300.)	15	1	15
15	1	14	1814.31938(11.)	3227.93760(20.)	4508.35566(300.)	4620.70750(80.)	15	1	14
15	2	14	1814.56604(8.)	3228.30752(9.)	4508.77909(100.)	4621.32810(100.)	15	2	14
15	2	13	1970.66094(9.)	3397.43789(10.)	4661.58600(300.)		15	2	13
15	3	13	1974.70833(11.)	3403.07160(12.)	4665.86286(300.)		15	3	13
15	3	12	2087.13891(15.)	3520.66220(20.)			15	3	12
15	4	12	2115.64485(10.)	3556.85918(15.)			15	4	12
15	4	11	2169.05922(10.)	3609.42165(10.)			15	4	11
15	5	11	2253.67218(10.)	3709.07672(15.)			15	5	11
15	5	10	2266.17555(20.)	3720.34805(40.)			15	5	10
15	6	10	2408.55705(15.)	3880.71488(15.)			15	6	10
15	6	9	2409.90330(15.)	3881.85040(25.)			15	6	9
15	7	9	2589.97264(10.)				15	7	9
15	7	8	2590.05749(10.)				15	7	8
15	8	8	2798.50894(20.)				15	8	8
15	8	7	2798.51279(15.)				15	8	7
15	9	7	3032.60555(20.)				15	9	7
15	9	6	3032.60555(20.)				15	9	6

Table 2 continued

J	K _a	k _c	(000)	(010)	(100)	(020)	J	K _a	k _c
16	0	16	1839.75388(20.)	3232.80368(15.)	4532.38976(300.)	4604.88652(80.)	16	0	16
16	1	16	1839.75700(20.)	3232.80859(15.)	4532.39529(300.)	4604.89377(80.)	16	1	16
16	1	15	2037.05842(10.)	3450.50120(12.)			16	1	15
16	2	15	2037.19025(15.)	3450.70525(20.)			16	2	15
16	2	14	2207.11685(15.)	3635.20060(15.)			16	2	14
16	3	14	2209.51629(10.)	3638.64843(30.)			16	3	14
16	3	13	2339.96000(400.)				16	3	13
16	4	13	2360.07559(80.)				16	4	13
16	4	12	2430.99215(50.)				16	4	12
16	5	12	2502.43743(20.)	3958.67827(20.)			16	5	12
16	5	11	2523.55936(30.)				16	5	11
16	6	11	2657.01290(30.)				16	6	11
16	6	10	2659.62250(40.)				16	6	10
16	7	10	2836.64400(900.)				16	7	10
16	7	9	2836.82293(15.)				16	7	9
16	8	9	3043.42041(20.)				16	8	9
16	8	8	3043.43039(20.)				16	8	8
16	9	8	3275.97815(15.)				16	9	8
16	9	7	3275.97815(15.)				16	9	7
17	0	17	2061.89679(60.)	3453.09215(40.)			17	0	17
17	1	17	2061.89829(30.)	3453.09445(40.)			17	1	17
17	1	16	2272.10235(15.)	3685.25893(20.)			17	1	16
17	2	16	2272.17235(15.)	3685.37104(20.)			17	2	16
17	2	15	2455.37930(15.)	3884.56479(100.)			17	2	15
17	3	15	2457.44900(300.)	3886.63082(25.)			17	3	15
17	4	13	2707.59515(40.)				17	4	13
17	6	12	2920.78306(30.)				17	6	12
17	7	10	3099.05774(80.)				17	7	10
18	0	18	2296.38400(300.)	3685.61872(70.)	4981.24779(300.)		18	0	18
18	1	18	2296.38400(300.)	3685.61872(70.)	4981.24779(300.)		18	1	18
18	1	17	2519.41562(20.)	3932.18848(30.)			18	1	17
18	2	17	2519.45239(20.)	3932.25022(30.)			18	2	17
19	0	19	2543.20885(90.)	3930.31480(40.)			19	0	19
19	1	19	2543.20923(90.)	3930.31480(40.)			19	1	19
19	1	18	2778.94900(500.)	4191.25586(20.)			19	1	18
19	2	18	2778.96900(500.)	4191.29079(20.)			19	2	18
20	0	20	2802.37980(100.)	4187.08473(40.)			20	0	20
20	1	20	2802.37980(100.)	4187.08473(40.)			20	1	20

Note. values given within parentheses are estimated uncertainties in the last digit(s)

Table 3. Matrix elements used in the expansion of the dipole moment for B-type transitions of water vapor.

j	n	$\langle J \ K A' (j) J' K' \rangle / \langle J \ K \Phi(x) J' K + \Delta K \rangle$	$\Delta K = \pm 1$
2	1	$J' (J'+1) + J(J+1)$	
3	1	$K'^2 + K^2$	
4	1	$K'^2 - K^2$	
5	1	$K'^2 - K^2 - 2m$	
6	1	$(K'^2 - K^2)(K'^2 - K^2 - 2m)$	
7	1	$J(J+1) - 2m(m-1) + (2m-1)K\Delta K - K^2 - 1$	
8	3	$[(J' - K\Delta K - 1) (J' - K\Delta K - 2) (J' + K\Delta K + 2) (J' + K\Delta K + 3)]^{1/2}$	
9	1	$K'^2 J' (J'+1) - K^2 J (J+1)$	
10	1	$K'^4 - K^4$	
11	1	$(K'^2 - K^2) [J' (J'+1) + J (J+1)]$	
12	1	$K'^2 (J'^2 + J')^2$	
13	1	K'^6	
14	1	K'^4	
15	1	$K'^2 J' (J'+1)$	
16	1	$K'^6 - K^6$	
17	1	$J' (J'+1) \text{ if } m=0 \text{ and } J=K_c \text{ or } J'=K_c', \text{ otherwise } = 0$	
18	1	$J' (J'+1) \text{ if } m=0 \text{ and } J=K_c \text{ or } J'=K_c'-1, \text{ otherwise } = 0$	
19	1	$J' (J'+1) \text{ if } m \neq 0 \text{ and } J=K_c \text{ and } J'=K_c', \text{ otherwise } = 0$	

$$J' - J = 0, \pm 1$$

$$m = [J' (J'+1) - J (J+1)]/2$$

$$K' - K = n\Delta K$$

Table 4. Matrix elements used in the expansion of the dipole moment for A-type transitions of water vapor.

j	n	$\langle J \ K A' (j) J' K' \rangle / \langle J \ K \Phi(z) J' K \rangle$	$\Delta K = \pm 1$
2	0	$J' (J'+1) + J(J+1)$	
3	0	$2K^2$	
4	0	m	
5	0	$2J(J+1) - 2m(m-1) - 2K^2 - 1$	
6	2	$\Delta K [(J' - K\Delta K - 1)(J' + K\Delta K + 2)]^* \times F$	
7	2	$2(K + \Delta K) [(J' - K\Delta K - 1)(J' + K\Delta K + 2)]^* \times F$	
8	2	$2\{K + \Delta K(1-m)\} [(J' - K\Delta K - 1)(J' + K\Delta K + 2)]^* \times F$	
9	2	$(K + \Delta K)[K'^2 - K^2] \times F$	
10	2	$(K + \Delta K)[K'^4 - K^4] \times F$	
11	1	mK'^2	
12	1	$2K'^2[J'(J'+1) + J(J+1)]$	
13	1	K'^4	
14	1	K'^6	

$$J' - J = 0, \pm 1$$

$$m = [J'(J'+1) - J(J+1)]/2$$

$$K' - K = n\Delta K$$

$$F = \langle J \ K | \Phi(z) | J' K \rangle / \langle J \ K | \Phi(x) | J' K + \Delta K \rangle$$

Table 5. Dipole moment expansion coefficients derived from least-squares fits of the (000)-(000), (010)-(000), (020)-(010), and (100)-(010) bands of HD¹⁶O^a. (Values in Debyes).

B-type transitions						
j	(010)-(000) band	(010)-(000) band	(010)-(000) band	(000)-(000) band	(020)-(010) band	(100)-(010) band
1	1.009(5)E-01	1.006(5)E-01	9.95(8)E-02	1.78(8)	1.554(7)E-01	7.92(4)E-03
2	3.26(16)E-05	2.31(12)E-05	1.81(10)E-05	2.18(11)E-03	2.58(12)E-05	1.78(15)E-05
3	2.10(10)E-04	1.20(6)E-04	-3.56(18)E-04	1.04(5)E-02	-1.66(8)E-05	-1.69(15)E-04
4	-4.53(23)E-03	-5.62(28)E-03	-4.12(21)E-03	-2.49(12)E-01	-8.72(44)E-03	3.75(25)E-04
5	-1.22(10)E-03	-8.28(41)E-04	-9.04(45)E-04	7.18(36)E-02	-1.37(69)E-03	-2.01(26)E-04
6	-4.03(20)E-05	-3.83(19)E-05	6.17(31)E-06	-1.04(6)E-03	-2.81(14)E-05	
7	3.44(17)E-05	3.25(16)E-05	2.03(10)E-05	5.82(29)E-03	7.43(37)E-05	
8	-4.08(20)E-05	-3.01(15)E-05	-1.82(9)E-05	6.23(31)E-06	-5.56(28)E-05	
9	-6.34(32)E-06	-7.03(35)E-06	6.04(30)E-07		-3.27(16)E-06	
10	2.19(11)E-05	9.52(48)E-06	-1.03(10)E-06	-1.71(9)E-05	1.53(8)E-05	
11	3.26(16)E-06	2.25(11)E-06	-9.08(45)E-08			
13	-9.57(48)E-08	6.44(32)E-08	-6.56(33)E-08			
14	-8.16(41)E-06	-3.87(19)E-06	1.43(8)E-05			
15	-1.87(10)E-06	-1.08(5)E-06	-6.77(34)E-07	-1.78(9)E-05		
16	-2.74(14)E-07	1.40(7)E-07	-3.52(18)E-08			
N ^b	392	228	172	67	236	40
$\sigma\%$ ^c	3.28	2.67	3.75	4.71	3.81	8.00
min v	850.243 cm ⁻¹	1401.065 cm ⁻¹	1600.548 cm ⁻¹	657.365 cm ⁻¹	1089.349 cm ⁻¹	1197.831 cm ⁻¹
max v	1396.323 cm ⁻¹	1598.446 cm ⁻¹	1941.746 cm ⁻¹	1029.595 cm ⁻¹	1810.076 cm ⁻¹	1421.912 cm ⁻¹
max S	1.90E-00	2.08E-00	5.32E-01	2.22E-03	3.81E-03	*1.97E-04
min S	2.04E-05	3.54E-05	3.85E-05	1.24E-05	1.53E-05	*1.36E-05
A-type transitions						
j	(010)-(000) band	(010)-(000) band	(020)-(010) band	(100)-(010) band		
1	7.76(23)E-02	7.73(23)E-02	1.097(3)E-01	1.303(5)E-02		
2	2.86(560)E-06	-6.13(610)E-06	-3.49(261)E-05	1.38(98)E-05		
3	-2.06(350)E-05	5.01(351)E-05	1.76(150)E-04			
4	-2.19(33)E-03	-2.10(21)E-03	-3.04(61)E-03	1.89(122)E-04		
5	-4.51(361)E-05			1.14(80)E-04		
6	4.77(72)E-04	2.26(34)E-04	1.59(255)E-04			
7	1.12(17)E-04	5.45(54)E-05				
8	1.47(88)E-05	1.44(36)E-05				
9	5.39(510)E-05	6.38(287)E-05	-4.59(321)E-05			
10	1.69(120)E-06	-1.39(49)E-06	2.77(166)E-06			
11	1.61(210)E-06	3.13(350)E-06	-2.15(129)E-05			
12						
13	-5.49(329)E-06	-2.38(143)E-06				
14	6.70(639)E-08	1.31(180)E-08				
N ^b	218	310	108	73		
$\sigma\%$ ^c	3.22	3.08	4.59	7.50		
min v	967.320 cm ⁻¹	1401.964 cm ⁻¹	1192.229 cm ⁻¹	1191.349 cm ⁻¹		
max v	1397.320 cm ⁻¹	2065.801 cm ⁻¹	1593.006 cm ⁻¹	1454.152 cm ⁻¹		
max S	1.30E-00	1.25E-00	2.84E-03	*3.15E-04		
min S	5.23E-05	2.27E-05	2.04E-05	*1.42E-05		

a. Values given within parentheses are uncertainties in the last digit(s).

b. N represents the number of line strengths used in the least-squares fits.

c. $\sigma\%$ is the standard deviation resulting from the least-squares fit in percent;

* major contribution of line strength in the (100)-(010) band due to borrowing from the (020)-(010) band

$$\sigma\% = \left\{ \sum [(S_{\text{obs}} - S_{\text{cal}})^2 / S_{\text{obs}}] \right\}^{1/2} \times 100.$$

line strengths, S, given in cm⁻²/atm.

Table 6. Perturbed levels in the (020) and (100) vibrational states of HD¹⁶O due mainly to strong Coriolis interactions.

----- (020) -----			----- (100) -----					
J	K _a	K _c	J	K _a	K _c	Δ ^c		
6	3	4	0.411	0.055	6	-0.411	-0.040	0.2716
6	2	5	-0.312	-0.047	6	0.312	0.047	-0.5158
4	1	4	-0.104	-0.006	4	0.104	0.006	-0.8862
3	2	2	0.047	0.005	3	-0.047	-0.004	0.8557

a. wavefunction mixing coefficient derived from experimental results

b. Δ is the frequency difference between the observed and computed positions of the level in cm⁻¹

c. δ is the differnce between the observed freqencies of the interacting levels in cm⁻¹

Table 7. Line positions and strengths ($\text{cm}^{-2}/\text{atm.}$ at 296K) of the (000)-(000) band of HD^{16}O .

observed position	o-c	upper J K _a K _c	lower J K _a K _c	lower energy	observed strength	t _s	computed strength	(o-c)%
657.36532	-14.	15 6 9	14 3 12	1752.53784	1.39E-03	2.	1.51E-03	-8.3
661.38546	16.	13 7 7	12 4 8	1481.44392	2.22E-03	1.	2.09E-03	5.8
661.81179	-6.	15 5 10	14 2 13	1604.36370	1.53E-03	2.	1.54E-03	-.5
663.71521	-5.	10 6 5	9 1 8	735.73515	1.91E-03	2.	1.94E-03	-1.4
665.25813	3.	14 7 8	13 4 9	1693.44335	1.24E-03	3.	1.19E-03	3.9
667.08425	0.	15 7 9	14 4 10	1922.88839	6.25E-04	5.	6.13E-04	2.0
674.90008	-4.	14 4 10	13 1 13	1247.98827	1.17E-03	2.	1.17E-03	-.4
677.01080	0.	13 7 6	12 4 9	1465.82976	2.34E-03	5.	2.23E-03	4.7
682.03913	-26.	12 5 8	11 0 11	916.02906	1.94E-03	0.	1.88E-03	3.0
684.99719	-4.	11 6 6	10 1 9	885.06459	2.01E-03	5.	1.98E-03	1.3
690.63732	0.	14 7 7	13 4 10	1668.09633	1.39E-03	6.	1.29E-03	7.7
698.16418	-18.	10 7 4	10 2 9	889.57588	3.26E-05	5.	3.28E-05	-.6
700.55826	-1.	8 6 2	7 1 7	404.44564	1.58E-04	2.	1.66E-04	-4.9
705.21483	0.	15 7 8	14 4 11	1884.84266	6.46E-04	5.	6.53E-04	-1.1
706.38527	3.	9 8 2	8 5 3	942.56218	1.21E-03	1.	1.23E-03	-1.4
706.41497	-1.	9 8 1	8 5 4	942.53244	1.22E-03	3.	1.23E-03	-.6
709.81139	-3.	12 6 7	11 1 10	1046.47441	1.61E-03	5.	1.61E-03	-.1
719.44874	4.	10 8 3	9 5 4	1082.88663	1.54E-03	2.	1.46E-03	5.2
719.55028	5.	10 8 2	9 5 5	1082.78510	1.51E-03	1.	1.46E-03	3.1
720.83484	-32.	12 7 6	12 2 11	1221.53740	2.69E-05	5.	2.68E-05	.2
721.17808	0.	16 7 9	15 4 12	2115.64485	2.93E-04	5.	3.03E-04	-3.2
725.49273	-3.	13 5 9	12 0 12	1075.71474	9.54E-04	2.	9.74E-04	-2.1
731.23257	-6.	9 6 3	8 1 8	513.20719	2.16E-04	3.	2.37E-04	-9.5
731.94109	0.	11 8 4	10 5 5	1239.08925	1.37E-03	1.	1.35E-03	1.5
732.23588	0.	11 8 3	10 5 6	1238.79446	1.37E-03	2.	1.35E-03	1.5
736.30079	-3.	15 4 11	14 1 14	1432.75840	3.42E-04	5.	3.73E-04	-8.7
738.09597	0.	13 6 8	12 1 11	1220.02912	1.11E-03	5.	1.06E-03	5.1
743.69690	1.	12 8 5	11 5 6	1411.32008	1.01E-03	2.	1.04E-03	-2.5
744.45018	8.	12 8 4	11 5 7	1410.56687	1.04E-03	3.	1.04E-03	-.2
754.47564	0.	13 8 6	12 5 7	1599.80023	6.91E-04	2.	6.89E-04	.3
756.20777	0.	13 8 5	12 5 8	1598.06845	6.92E-04	1.	6.96E-04	-.6
763.94263	6.	14 8 7	13 5 8	1804.84019	3.87E-04	5.	4.01E-04	-3.6
767.57601	-16.	14 8 6	13 5 9	1801.20750	3.89E-04	5.	4.09E-04	-5.1
769.74575	-6.	14 6 9	13 1 12	1405.81844	5.31E-04	7.	5.79E-04	-8.7
771.67679	0.	15 8 8	14 5 9	2026.83215	2.12E-04	5.	2.09E-04	1.6
778.68979	0.	15 8 7	14 5 10	2019.82300	2.13E-04	5.	2.16E-04	-1.5
780.48346	1.	9 7 3	8 2 6	653.08875	8.96E-05	5.	9.35E-05	-4.3
* 784.50383	24.	9 9 1	8 6 2	1105.00391	3.09E-04	5.	3.19E-04	-3.3
786.09611	-6.	10 7 4	9 2 7	801.64407	1.59E-04	5.	1.71E-04	-7.3
792.49051	-3.	11 7 5	10 2 8	964.85063	2.39E-04	5.	2.45E-04	-2.6
* 797.66669	131.	10 9 2	9 6 3	1244.43982	6.16E-04	5.	5.59E-04	9.7
800.68083	1.	12 7 6	11 2 9	1141.69174	2.95E-04	5.	2.83E-04	4.1
800.96415	0.	16 4 12	15 1 15	1630.02800	1.09E-04	5.	1.11E-04	-2.1
800.97929	0.	11 6 5	10 1 10	769.11689	1.82E-04	5.	1.82E-04	-.1
804.65109	-13.	15 6 10	14 1 13	1603.90583	2.97E-04	5.	2.74E-04	8.2
810.44499	-9.	11 9 3	10 6 4	1399.46074	3.20E-04	16.	3.06E-04	4.5
810.45550	9.	11 9 2	10 6 5	1399.45041	2.99E-04	11.	3.06E-04	-2.4
811.61229	3.	13 7 7	12 2 10	1331.21696	2.75E-04	5.	2.65E-04	3.6
820.92546	-8.	15 5 11	14 0 14	1432.74664	1.80E-04	5.	1.74E-04	3.4
822.78963	-4.	12 9 4	11 6 5	1570.09618	2.50E-04	5.	2.60E-04	-3.8
822.82401	-2.	12 9 3	11 6 6	1570.06182	2.51E-04	5.	2.59E-04	-3.3
823.62554	-15.	9 7 2	8 2 7	609.94656	5.57E-05	28.	6.26E-05	-11.7
825.96917	-12.	14 7 8	13 2 11	1532.73216	1.82E-04	7.	2.02E-04	-10.3
834.63339	-5.	13 9 5	12 6 6	1756.38491	1.77E-04	5.	1.84E-04	-3.8
834.73266	14.	13 9 4	12 6 7	1756.28583	1.83E-04	5.	1.85E-04	-.9
840.26098	8.	12 6 6	11 1 11	916.12401	1.56E-04	24.	1.57E-04	-.6
842.69352	0.	16 6 11	15 1 14	1814.31938	1.29E-04	16.	1.12E-04	14.0
844.07576	6.	15 7 9	14 2 12	1745.89694	1.15E-04	5.	1.25E-04	-8.0
844.64285	-23.	10 7 3	9 2 8	743.09739	8.00E-05	6.	9.18E-05	-13.7
845.88775	-20.	14 9 6	13 6 7	1958.38311	1.10E-04	5.	1.13E-04	-3.1
846.14617	20.	14 9 5	13 6 8	1958.12509	1.17E-04	5.	1.14E-04	2.8
856.42792	7.	15 9 7	14 6 8	2176.17770	5.84E-05	19.	6.18E-05	-5.7
857.04123	-7.	15 9 6	14 6 9	2175.56425	6.44E-05	13.	6.22E-05	3.5
866.07477	-8.	16 9 8	15 6 9	2409.90330	2.95E-05	5.	3.03E-05	-2.6
867.42116	6.	16 9 7	15 6 10	2408.55705	2.73E-05	8.	3.05E-05	-11.0

Table 7. continued

observed position	o-c	upper J K _a K _c	lower J K _a K _c	lower energy	observed strength	%s	computed strength	(o-c)%
867.76611	-15.	11 7 4	10 2 9	889.57588	9.63E-05	5.	1.01E-04	-5.1
867.83815	0.	17 4 13	16 1 16	1839.75700	3.36E-05	16.	3.19E-05	5.3
872.41467	0.	16 5 12	15 0 15	1630.02276	6.54E-05	5.	6.15E-05	6.1
* 872.54027	2.	10 10 1	9 7 2	1433.57225	6.39E-05	5.	6.00E-05	6.4
882.62069	5.	13 6 7	12 1 12	1075.76247	1.00E-04	5.	1.07E-04	-6.7
883.72464	0.	17 6 12	16 1 15	2037.05842	3.64E-05	16.	4.08E-05	-11.4
* 885.23380	7.	11 10 2	10 7 3	1587.74047	1.00E-04	5.	9.74E-05	2.7
893.25153	0.	12 7 5	11 2 10	1049.12452	8.99E-05	5.	8.94E-05	.5
* 909.53330	178.	13 10 4	12 7 5	1942.37605	8.52E-05	1.	8.08E-05	5.3
921.07186	11.	14 10 5	13 7 6	2142.84056	2.68E-05	5.	2.73E-05	-1.9
921.08284	-25.	14 10 4	13 7 7	2142.82922	2.45E-05	5.	2.73E-05	-10.9
942.94312	34.	10 8 3	9 3 6	859.39255	1.24E-05	5.	1.28E-05	-3.3
1029.59450	0.	16 6 10	15 1 15	1630.02800	2.01E-05	6.	1.74E-05	14.1

positions and lower energies in cm⁻¹o-c, observed minus computed line positions $\times 10^5$. The computed values are derived from the energy levels given in Table 2

%s are the estimated uncertainties in the measured line strengths in percent.

(%-c)%, observed minus computed line strength values given in percent. Computed value are derived from constants obtained in this work and given in Table 5 for the (000)-(000) band.

asterisks denote doubled absorptions with the quantum assignment given for one of the transitions. The strength given represents the sum of the strengths of the two comparable transitions.

Strengths normalized to 99.9% HD¹⁶O.

Table 8. Line positions and strengths ($\text{cm}^{-2}/\text{atm.}$ at 296K) for the far R-branch A-type transitions of the (010)-(000) band of HD^{16}O .

observed position	o-c	upper J	K_a	K_c	lower J	K_a	K_c	lower energy	observed strength	$\pm s$	computed strength	(o-c) \pm	ℓ	f
1665.26011	-4.	8	2	6	7	0	7	403.16148	8.90E-04	2.	8.86E-04	.4	1.82E-01	5.18E-01
*1671.83969	-55.	19	1	18	18	1	17	2519.41562	2.27E-05	4.	2.36E-05	-4.0	4.30E+00	4.32E-01
1672.01652	0.	15	4	12	14	4	11	1884.84266	3.98E-04	4.	3.94E-04	1.1	3.73E+00	6.14E-01
1672.90609	-4.	13	6	8	12	6	7	1756.28583	6.98E-04	2.	7.07E-04	-1.3	3.20E+00	7.01E-01
1673.02483	-10.	13	6	7	12	6	6	1756.38491	7.01E-04	2.	7.07E-04	-.9	3.20E+00	7.01E-01
1673.27031	-19.	14	5	10	13	5	9	1801.20750	5.95E-04	3.	6.00E-04	-.8	3.50E+00	6.59E-01
*1674.23063	-73.	12	7	5	11	7	4	1757.34214	1.23E-03	5.	1.21E-03	1.6	2.82E+00	7.39E-01
1675.90529	-2.	14	5	9	13	5	8	1804.84019	5.83E-04	3.	5.92E-04	-1.5	3.51E+00	6.58E-01
*1677.02799	9.	11	8	3	10	8	2	1802.33533	6.90E-04	2.	6.97E-04	-.9	2.28E+00	7.72E-01
1677.11434	-19.	17	3	15	16	3	14	2209.51629	7.40E-05	7.	7.19E-05	2.8	4.03E+00	5.34E-01
1679.95330	-3.	4	4	0	3	2	1	157.06471	1.35E-04	4.	1.32E-04	2.0	6.19E-02	3.21E-01
*1680.71791	8.	10	9	1	9	9	0	1889.50750	1.76E-04	5.	1.82E-04	-3.5	1.38E+00	8.06E-01
1681.62728	-4.	4	4	1	3	2	2	155.38900	1.31E-04	5.	1.25E-04	5.1	6.15E-02	3.12E-01
1686.53319	-7.	15	4	11	14	4	10	1922.88839	3.43E-04	4.	3.36E-04	2.0	3.76E+00	6.14E-01
1689.30349	-25.	14	6	8	13	6	7	1958.38311	2.72E-04	4.	2.79E-04	-2.4	3.39E+00	6.76E-01
1691.16104	-6.	7	3	5	6	1	6	308.61570	4.02E-04	2.	4.21E-04	-4.7	1.29E-01	3.96E-01
*1692.77134	20.	12	8	4	11	8	3	1971.03034	4.00E-04	2.	3.78E-04	5.7	2.58E+00	7.52E-01
1693.36666	-1.	5	4	1	4	2	2	221.83613	2.20E-04	5.	2.44E-04	-10.5	9.38E-02	3.36E-01
1693.51621	31.	15	5	10	14	5	9	2026.83215	2.02E-04	4.	2.05E-04	-1.5	3.67E+00	6.32E-01
*1696.30815	-2.	11	9	2	10	9	1	2042.10520	1.55E-04	4.	1.60E-04	-3.1	1.91E+00	7.86E-01
1705.00613	4.	16	5	12	15	5	11	2253.67218	6.59E-05	10.	6.80E-05	-3.2	3.80E+00	6.07E-01
1705.15053	-10.	15	6	10	14	6	9	2175.56425	9.74E-05	10.	1.00E-04	-3.0	3.56E+00	6.52E-01
1705.67251	-19.	15	6	9	14	6	8	2176.17770	9.90E-05	6.	1.00E-04	-1.1	3.56E+00	6.52E-01
1705.78292	6.	9	2	7	8	0	8	512.51582	2.17E-04	6.	2.30E-04	-5.7	1.56E-01	3.96E-01
1706.07084	8.	14	7	8	13	7	7	2142.82922	1.12E-04	6.	1.11E-04	1.0	3.24E+00	6.94E-01
1706.08564	-5.	14	7	7	13	7	6	2142.84056	1.13E-04	6.	1.11E-04	1.8	3.24E+00	6.94E-01
*1708.51211	-7.	13	8	5	12	8	4	2155.01697	1.76E-04	3.	1.79E-04	-1.7	2.84E+00	7.32E-01
*1711.89793	6.	12	9	3	11	9	2	2209.90582	1.00E-04	10.	9.83E-05	1.7	2.29E+00	7.68E-01
1713.58624	-10.	10	3	7	9	1	8	735.73515	3.10E-04	5.	3.28E-04	-5.7	2.90E-01	4.36E-01
1720.53104	-5.	8	3	6	7	1	7	404.44564	1.58E-04	17.	1.62E-04	-2.5	1.30E-01	3.06E-01
1747.59545	0.	11	3	8	10	1	9	885.06459	6.91E-05	9.	7.73E-05	-11.2	2.61E-01	3.34E-01
1875.47352	-10.	7	6	1	6	4	2	573.97061	5.38E-05	0.	5.41E-05	-.5	8.58E-02	-3.86E-01
1875.55343	2.	7	6	2	6	4	3	573.89076	5.58E-05	4.	5.42E-05	2.9	8.58E-02	-3.86E-01
1890.08594	-30.	8	6	2	7	4	3	683.61010	5.51E-05	5.	5.30E-05	4.0	1.09E-01	-3.93E-01
1890.37164	-25.	8	6	3	7	4	4	683.32398	5.73E-05	2.	5.36E-05	6.7	1.09E-01	-3.95E-01
1904.15397	-1.	9	6	3	8	4	4	809.39325	4.88E-05	21.	4.28E-05	13.2	1.29E-01	-4.01E-01
1917.38146	-1.	10	6	4	9	4	5	951.63565	3.04E-05	22.	3.11E-05	-2.4	1.46E-01	-4.25E-01
1933.83585	13.	11	6	6	10	4	7	1106.26439	2.13E-05	24.	2.08E-05	2.5	1.66E-01	-4.44E-01
1964.25664	-8.	8	7	1	7	5	2	818.01365	5.74E-05	9.	6.48E-05	-12.1	8.39E-02	-7.64E-01
1964.26377	7.	8	7	2	7	5	3	818.00667	5.74E-05	9.	6.48E-05	-12.1	8.39E-02	-7.65E-01
1978.86956	0.	9	7	3	8	5	4	942.53244	5.21E-05	8.	5.92E-05	-12.7	1.06E-01	-7.80E-01
1993.11304	-8.	10	7	3	9	5	4	1082.88663	4.31E-05	6.	4.38E-05	-1.7	1.26E-01	-7.92E-01
1993.21445	11.	10	7	4	9	5	5	1082.78510	4.22E-05	6.	4.40E-05	-4.1	1.26E-01	-7.93E-01
2021.00440	9.	12	7	6	11	5	7	1410.56687	1.75E-05	12.	1.59E-05	9.9	1.63E-01	-8.08E-01
*2036.88492	21.	8	8	1	7	6	2	981.12801	5.09E-05	1.	4.96E-05	2.6	5.60E-02	-1.03E+00
*2065.80085	131.	10	8	2	9	6	3	1244.43982	5.82E-05	3.	6.11E-05	-4.9	1.04E-01	-1.16E+00

positions and lower energies in cm^{-1}

o-c , observed minus computed line positions $\times 10^5$. The computed values are derived from the energy levels given in Table 2

$\pm s$ are the estimated uncertainties in the measured line strengths in percent.

$(\text{o-c})\%$, observed minus computed line strength values given in percent. Computed value are derived from constants obtained in this work and given in Table 5 for the A-type transitions of the (010)-(000) band.

*asterisks denote doubled absorptions with the quantum assignment given for one of the transitions.

The strength given represents the sum of the strengths of the two comparable transitions.

ℓ is the direction cosine matrix element and f is the f-factor defined in eq. (13)

Strengths normalized to 99.9% HD^{16}O .

Table 9. Line positions and strengths (cm⁻²/atm. at 296K)
of the B-type transitions of the (020)-(010) band of HD¹⁶O.

observed position	o-c	upper J K _a K _c	lower J K _a K _c	observed strength	#s	computed strength	(o-c)‡	Z1 ^a	Z2 ^a	Z3 ^a
1089.34857	-16.	6 0 6	7 3 5	2.92E-05	3.	3.01E-05	-3.1	-5.49E-03	2.27E-06	-2.72E-06
*1108.12994	-76.	8 6 3	9 7 2	4.56E-05	14.	4.10E-05	10.0	6.43E-03	-1.98E-05	3.36E-08
1119.33780	-14.	7 1 7	8 2 6	5.64E-05	4.	5.96E-05	-5.6	7.70E-03	1.17E-05	6.21E-06
*1122.62867	6.	7 6 2	8 7 1	8.43E-05	8.	8.30E-05	1.6	9.14E-03	-2.80E-05	-4.07E-08
1127.17759	-6.	8 4 5	9 5 4	9.48E-05	9.	8.02E-05	15.4	8.97E-03	-1.22E-05	-4.48E-06
1129.73168	-22.	8 2 7	9 3 6	8.86E-05	10.	8.16E-05	7.9	9.01E-03	6.51E-06	1.74E-05
*1137.27280	-5.	6 6 0	7 7 1	1.57E-04	7.	1.56E-04	.6	1.25E-02	-3.85E-05	2.62E-08
1142.14194	-6.	7 4 3	8 5 4	1.65E-04	7.	1.62E-04	1.5	1.28E-02	-1.47E-05	-6.57E-06
1155.83732	27.	7 3 5	8 4 4	2.44E-04	4.	2.30E-04	5.9	1.52E-02	-2.59E-06	-1.26E-05
1157.77424	-5.	7 2 6	8 3 5	1.78E-04	6.	1.99E-04	-11.0	1.40E-02	1.71E-05	3.82E-05
1159.14159	-11.	8 0 8	8 3 5	1.70E-05	15.	1.64E-05	3.5	4.04E-03	8.17E-06	3.78E-06
1161.23950	-5.	7 3 4	8 4 5	2.36E-04	5.	2.29E-04	2.8	1.52E-02	-7.48E-07	-1.89E-05
1171.62603	3.	5 4 2	6 5 1	5.22E-04	3.	5.25E-04	-.5	2.29E-02	-2.83E-05	7.09E-07
1171.64001	-12.	5 4 1	6 5 2	5.05E-04	5.	5.25E-04	-3.9	2.29E-02	-2.82E-05	7.11E-07
1174.03075	-6.	6 3 3	7 4 4	4.36E-04	3.	4.35E-04	.1	2.09E-02	-1.90E-08	-1.43E-05
*1186.70151	-70.	4 0 5	5 5 1	1.70E-03	3.	1.70E-03	.3	4.12E-02	-5.64E-05	1.13E-07
1193.86597	7.	5 1 5	6 2 4	3.10E-04	4.	3.18E-04	-2.6	1.77E-02	6.75E-05	1.99E-05
1194.25132	-3.	8 2 6	9 3 7	1.33E-04	5.	1.35E-04	-1.8	1.16E-02	2.83E-05	-1.14E-05
1199.51370	0.	7 2 5	8 3 6	2.51E-04	6.	2.66E-04	-5.9	1.63E-02	3.96E-05	-1.44E-05
1202.60729	-10.	4 3 2	5 4 1	1.20E-03	5.	1.21E-03	-.9	3.48E-02	6.99E-06	4.60E-06
1202.79385	-1.	4 3 1	5 4 2	1.20E-03	2.	1.21E-03	-.9	3.48E-02	7.15E-06	4.74E-06
1202.82345	-1.	5 2 4	6 3 3	8.19E-04	4.	7.96E-04	2.8	2.81E-02	5.95E-05	3.36E-05
1205.46828	-9.	12 0 12	13 1 13	3.71E-05	9.	4.08E-05	-10.0	6.34E-03	7.43E-05	-2.76E-05
1205.61572	0.	12 1 12	13 0 13	3.75E-05	2.	4.08E-05	-8.8	-6.34E-03	-7.42E-05	2.76E-05
1206.55913	-2.	6 2 4	7 3 5	4.84E-04	6.	4.92E-04	-1.6	2.21E-02	5.44E-05	-1.05E-05
1215.68768	-9.	5 2 3	6 3 4	8.61E-04	4.	8.48E-04	1.5	2.91E-02	7.31E-05	-2.49E-05
1215.97408	20.	12 1 12	12 2 11	4.79E-05	5.	4.78E-05	.3	-6.83E-03	-5.74E-05	-1.93E-05
1218.65632	3.	11 0 11	12 1 12	8.56E-05	8.	9.01E-05	-5.3	9.42E-03	1.03E-04	-3.35E-05
1218.93272	-8.	11 1 11	12 0 12	9.18E-05	9.	9.00E-05	1.9	-9.42E-03	-1.03E-04	3.33E-05
1223.09463	-14.	10 1 9	11 2 10	7.18E-05	6.	6.71E-05	6.6	8.16E-03	4.28E-05	-1.50E-05
PR1225.13874	3.	4 1 4	5 2 3	5.71E-04	4.	6.39E-04	-12.0	2.55E-02	1.17E-04	-3.48E-04
1226.97780	-4.	4 2 2	5 3 3	1.38E-03	4.	1.35E-03	1.9	3.67E-02	9.51E-05	-3.77E-05
1230.88049	6.	11 1 11	11 2 10	1.08E-04	7.	1.00E-04	7.1	-9.91E-03	-8.19E-05	-2.17E-05
1238.28481	-11.	3 2 2	4 3 1	2.01E-03	2.	2.00E-03	.4	4.45E-02	9.08E-05	1.52E-04
1238.71394	-20.	8 1 7	9 2 8	2.53E-04	4.	2.50E-04	1.2	1.57E-02	8.61E-05	-2.00E-05
1240.17859	-5.	3 2 1	4 3 2	2.01E-03	2.	2.00E-03	.5	4.47E-02	9.32E-05	-9.80E-05
1244.55581	-1.	9 0 9	10 1 10	3.39E-04	5.	3.55E-04	-4.8	1.87E-02	1.84E-04	-4.35E-05
1245.29719	-8.	7 1 6	8 2 7	4.27E-04	3.	4.32E-04	-1.2	2.07E-02	1.16E-04	-2.17E-05
*1246.29165	-33.	7 6 1	7 7 0	2.72E-05	10.	2.81E-05	-3.2	-5.31E-03	1.12E-05	1.64E-06
1250.82747	25.	10 0 10	10 1 9	2.12E-04	8.	2.04E-04	3.7	-1.41E-02	-1.19E-04	-2.41E-05
1251.70273	-8.	6 1 5	7 2 6	7.32E-04	3.	6.94E-04	5.2	2.62E-02	1.51E-04	-2.26E-05
1252.19109	-4.	3 1 3	4 2 2	1.21E-03	3.	1.21E-03	.0	3.46E-02	1.91E-04	-4.89E-05
*1253.89575	-5.	6 5 2	6 6 1	1.21E-04	5.	1.23E-04	-1.3	-1.11E-02	1.40E-05	5.18E-06
1257.09772	-9.	9 5 4	9 6 3	3.63E-05	12.	3.59E-05	1.1	-5.99E-03	3.81E-06	-5.34E-06
1257.13815	-2.	8 0 8	9 1 9	6.13E-04	4.	6.32E-04	-3.0	2.49E-02	2.38E-04	-4.65E-05
1258.55206	-21.	5 1 4	6 2 5	1.02E-03	4.	1.04E-03	-2.0	3.21E-02	1.89E-04	-2.24E-05
1258.86931	-4.	8 1 8	9 0 9	6.44E-04	9.	6.25E-04	2.9	-2.48E-02	-2.36E-04	4.59E-05
1259.27742	2.	9 1 9	9 2 8	3.72E-04	7.	3.66E-04	1.7	-1.89E-02	-1.53E-04	-2.36E-05
1264.47135	-20.	11 2 10	11 3 9	9.46E-05	8.	8.97E-05	5.1	-9.41E-03	-5.13E-05	-8.89E-06
1265.12419	2.	5 4 2	5 5 1	2.07E-04	5.	2.11E-04	-1.8	-1.45E-02	2.45E-06	3.71E-06
1265.13710	-9.	5 4 1	5 5 0	2.19E-04	4.	2.11E-04	3.7	-1.45E-02	2.44E-06	3.74E-06
1265.83031	4.	8 2 7	9 1 8	2.03E-04	8.	2.05E-04	-.8	-1.42E-02	-7.70E-05	1.95E-05
1265.88373	-14.	6 4 3	6 5 2	2.40E-04	5.	2.54E-04	-5.7	-1.59E-02	-5.44E-07	9.28E-06
1266.37631	-3.	4 1 3	5 2 4	1.46E-03	2.	1.47E-03	-.4	3.81E-02	2.32E-04	-2.07E-05
1266.83029	3.	7 4 4	7 5 3	2.09E-04	10.	2.17E-04	-3.8	-1.47E-02	-3.41E-06	-3.12E-05
1267.85395	-3.	9 0 9	9 1 8	3.73E-04	4.	3.84E-04	-3.1	-1.94E-02	-1.65E-04	-2.52E-05
1268.59426	11.	8 4 4	8 5 3	1.54E-04	6.	1.54E-04	.1	-1.24E-02	-6.65E-06	-2.76E-05
1272.41462	7.	7 1 7	8 0 8	9.73E-04	2.	1.02E-03	-4.4	-3.16E-02	-2.95E-04	4.66E-05
1275.30320	-1.	2 1 2	3 2 1	1.19E-03	1.	1.91E-03	-.7	4.35E-02	2.73E-04	-1.44E-05
1275.54031	-4.	3 1 2	4 2 3	1.96E-03	1.	1.94E-03	.9	4.38E-02	2.76E-04	-1.70E-05
1280.16664	7.	10 3 8	10 4 7	1.16E-04	3.	1.14E-04	1.5	-1.06E-02	-3.42E-05	-2.44E-05
1280.79386	0.	4 3 2	4 4 1	5.71E-04	3.	5.66E-04	.9	-2.38E-02	-3.78E-05	1.72E-05
1280.96349	-3.	4 3 1	4 4 0	5.43E-04	1.	5.66E-04	-4.2	-2.38E-02	-3.79E-05	1.79E-05
1281.32719	-5.	5 3 3	5 4 2	7.30E-04	5.	7.26E-04	.6	-2.69E-02	-4.39E-05	5.14E-05
1281.57003	-7.	9 2 8	9 3 7	3.43E-04	4.	3.44E-04	-.2	-1.84E-02	-9.78E-05	2.26E-07

table 9 continued

observed position	o-c	upper J	K _a	K _c	lower J	K _a	K _c	observed strength	ts	computed strength	(o-c)‡	Z1 ^a	Z2 ^a	Z3 ^a
PR1281.92517	1.	6	3	4	6	4	3	4.55E-04	4.	4.90E-04	-7.7	-2.32E-02	-5.03E-05	1.15E-03
1281.98312	-14.	5	3	2	5	4	1	7.53E-04	1.	7.25E-04	3.7	-2.69E-02	-4.20E-05	6.43E-05
1282.27274	6.	7	3	5	7	4	4	5.18E-04	3.	5.14E-04	.7	-2.26E-02	-5.24E-05	-4.18E-05
1284.49748	-6.	7	1	7	7	2	6	1.02E-03	2.	1.01E-03	1.2	-3.15E-02	-2.51E-04	-1.85E-05
1284.74334	-26.	9	3	7	10	2	8	2.76E-05	10.	2.61E-05	5.4	-5.10E-03	-1.60E-05	5.15E-06
1285.11979	7.	8	0	8	8	1	7	6.73E-04	3.	6.88E-04	-2.2	-2.60E-02	-2.24E-04	-2.53E-05
1286.25138	2.	2	1	1	3	2	2	2.38E-03	2.	2.40E-03	-.9	4.87E-02	3.21E-04	-1.04E-05
1286.31405	-27.	6	1	6	7	0	7	1.50E-03	2.	1.51E-03	-1.0	-3.86E-02	-3.58E-04	4.44E-05
1286.63623	9.	7	3	4	7	4	3	4.90E-04	3.	5.14E-04	-4.9	-2.26E-02	-5.28E-05	-6.00E-05
1290.97323	-19.	8	3	5	8	4	4	3.19E-04	4.	3.47E-04	-8.9	-1.85E-02	-5.43E-05	-3.49E-05
1293.05249	0.	7	2	6	7	3	5	9.25E-04	4.	9.14E-04	1.2	-3.01E-02	-1.45E-04	5.68E-05
1295.17126	-1.	1	1	1	2	2	0	2.63E-03	2.	2.63E-03	.2	5.09E-02	3.49E-04	5.20E-07
1295.36420	-22.	6	1	6	6	2	5	1.43E-03	3.	1.48E-03	-3.8	-3.82E-02	-3.03E-04	-1.14E-05
PR1296.64977	3.	6	2	5	6	3	4	1.32E-03	2.	1.28E-03	3.0	-3.46E-02	-1.62E-04	-9.81E-04
1298.60060	6.	1	0	2	2	1	1	2.79E-03	1.	2.82E-03	-1.0	5.27E-02	3.67E-04	0.00E+00
1299.11841	7.	5	2	4	5	3	3	1.50E-03	2.	1.56E-03	-4.0	-3.94E-02	-1.83E-04	5.76E-05
1300.50545	-3.	4	2	3	4	3	2	1.56E-03	2.	1.59E-03	-1.7	-3.97E-02	-1.71E-04	9.52E-05
1300.79557	-8.	5	1	5	6	0	6	1.94E-03	3.	2.03E-03	-4.8	-4.47E-02	-4.17E-04	3.94E-05
PR1301.14766	-12.	3	2	2	3	3	1	1.12E-03	4.	1.15E-03	-2.5	-3.41E-02	-1.08E-04	2.40E-04
1302.11802	-4.	7	0	7	7	1	6	1.13E-03	2.	1.17E-03	-3.7	-3.39E-02	-2.97E-04	-2.46E-05
1302.40680	-9.	4	0	4	5	1	5	2.65E-03	1.	2.73E-03	-3.0	5.18E-02	5.06E-04	-3.56E-05
1302.94886	-9.	10	1	9	10	2	8	2.34E-04	3.	2.39E-04	-2.3	-1.54E-02	-9.64E-05	-1.52E-05
PR1303.16506	-2.	6	2	5	7	1	6	3.68E-04	2.	3.85E-04	-4.5	-1.97E-02	-1.17E-04	2.54E-04
1304.80798	-6.	5	1	5	5	2	4	1.93E-03	2.	1.97E-03	-2.1	-4.40E-02	-3.48E-04	3.66E-06
1305.24428	-28.	4	2	2	4	3	1	1.45E-03	5.	1.63E-03	-12.5	-4.01E-02	-1.84E-04	-7.96E-05
1308.59485	3.	8	3	6	9	2	7	4.72E-05	7.	4.14E-05	12.3	-6.42E-03	-2.18E-05	5.72E-06
1308.92290	17.	13	2	11	13	3	10	1.56E-05	6.	1.62E-05	-3.7	-4.00E-03	-1.63E-05	-5.41E-06
1309.14817	-7.	5	2	3	5	3	2	1.61E-03	3.	1.63E-03	-1.3	-4.01E-02	-2.02E-04	-4.82E-05
1311.07502	-8.	11	3	8	11	4	7	5.93E-05	5.	5.96E-05	-.5	-7.67E-03	-3.39E-05	-1.06E-05
1312.49499	32.	3	0	3	4	1	4	2.58E-03	15.	3.13E-03	-21.3	5.54E-02	5.58E-04	-2.74E-05
PR1312.69279	-4.	4	1	4	4	2	3	2.33E-03	3.	2.37E-03	-1.5	-4.79E-02	-3.65E-04	-4.16E-04
1314.25300	4.	6	2	4	6	3	3	1.37E-03	2.	1.40E-03	-2.0	-3.71E-02	-2.03E-04	-3.46E-05
1317.41637	5.	12	3	9	12	4	8	2.39E-05	10.	2.75E-05	-15.2	-5.22E-03	-2.46E-05	-7.21E-06
1318.00217	-2.	6	0	6	6	1	5	1.87E-03	2.	1.92E-03	-2.4	-4.34E-02	-3.86E-04	-2.30E-05
1318.52645	0.	12	2	10	12	3	9	4.13E-05	4.	4.29E-05	-3.9	-6.51E-03	-3.03E-05	-7.38E-06
1318.97941	-2.	3	1	3	3	2	2	2.29E-03	2.	2.33E-03	-1.9	-4.79E-02	-3.74E-04	-7.16E-05
1319.73581	-4.	7	2	5	7	3	4	1.04E-03	1.	1.05E-03	-1.3	-3.22E-02	-1.89E-04	-2.67E-05
1323.63723	-2.	2	1	2	2	1	1	1.69E-03	2.	1.71E-03	-1.1	-4.10E-02	-3.24E-04	-3.07E-05
1323.78311	0.	5	2	4	6	1	5	4.82E-04	3.	4.83E-04	-.1	-2.18E-02	-1.45E-04	1.66E-05
1326.74649	-8.	8	1	7	8	2	6	9.14E-04	6.	9.73E-04	-6.4	-3.10E-02	-2.17E-04	-1.93E-05
1327.40099	-2.	9	2	7	9	3	6	4.11E-04	2.	4.26E-04	-3.6	-2.05E-02	-1.26E-04	-1.66E-05
1327.68127	-17.	10	2	8	10	3	7	2.16E-04	4.	2.23E-04	-3.3	-1.48E-02	-8.86E-05	-1.29E-05
1331.81843	4.	5	0	5	5	1	4	2.87E-03	1.	2.95E-03	-2.9	-5.39E-02	-4.82E-04	-2.10E-05
1332.31838	-8.	3	1	3	4	0	4	2.42E-03	3.	2.42E-03	-.2	-4.88E-02	-4.79E-04	2.64E-05
1332.50952	-3.	2	1	1	2	2	0	2.00E-03	1.	2.04E-03	-2.2	-4.48E-02	-3.63E-04	-1.92E-05
1332.79626	-1.	7	3	5	8	2	6	5.65E-05	9.	5.99E-05	-5.9	-7.71E-03	-2.96E-05	6.86E-06
1333.99284	-4.	7	1	6	7	2	5	1.62E-03	2.	1.69E-03	-4.1	-4.07E-02	-3.10E-04	-2.09E-05
1334.10410	2.	1	0	1	2	1	2	2.98E-03	2.	3.05E-03	-2.4	5.47E-02	5.59E-04	-8.63E-06
1335.65797	0.	3	1	2	3	2	1	3.18E-03	2.	3.19E-03	-.5	-5.60E-02	-4.64E-04	-2.24E-05
1338.06381	1.	6	1	5	6	2	4	2.47E-03	2.	2.56E-03	-3.8	-5.02E-02	-4.07E-04	-2.22E-05
1338.24653	2.	4	1	3	4	2	2	3.60E-03	2.	3.62E-03	-.6	-5.97E-02	-5.00E-04	-2.33E-05
1339.30246	-23.	5	1	4	5	2	3	3.25E-03	1.	3.34E-03	-2.7	-5.73E-02	-4.79E-04	-2.30E-05
1342.85493	-17.	4	0	4	4	1	3	4.03E-03	5.	4.14E-03	-2.6	-6.37E-02	-5.72E-04	-1.85E-05
1344.82352	5.	4	2	3	5	1	4	5.06E-04	5.	4.85E-04	4.1	-2.19E-02	-1.52E-04	1.36E-05
1346.71105	0.	0	0	0	1	1	1	2.41E-03	2.	2.43E-03	-.9	4.88E-02	5.18E-04	0.00E+00
1349.27195	2.	2	1	2	3	0	3	2.05E-03	1.	1.99E-03	3.0	-4.42E-02	-4.57E-04	1.63E-05
1350.90244	-7.	3	0	3	3	1	2	4.88E-03	1.	5.03E-03	-3.2	-7.03E-02	-6.51E-04	-1.58E-05
1356.24690	-18.	2	0	2	2	1	1	5.08E-03	2.	5.03E-03	.9	-7.02E-02	-7.15E-04	-1.30E-05
1359.40926	-1.	1	0	1	1	0	1	3.78E-03	2.	3.77E-03	.2	-6.07E-02	-6.72E-04	-9.94E-06
1365.23775	13.	3	1	3	2	2	0	2.82E-04	16.	2.95E-04	-4.7	-1.70E-02	-1.52E-04	-5.84E-05
1366.41941	3.	1	1	2	0	2	1	1.12E-03	2.	1.12E-03	-.3	-3.32E-02	-3.62E-04	7.71E-06
1370.85888	35.	7	1	7	6	2	4	1.13E-04	8.	1.13E-04	-.2	-1.05E-02	-8.73E-05	9.62E-07
PR1372.81056	11.	4	1	4	3	2	1	4.10E-04	2.	4.40E-04	-7.4	-2.03E-02	-1.81E-04	-5.06E-04
1376.11453	-31.	6	1	6	5	2	3	2.10E-04	4.	2.22E-04	-5.6	-1.48E-02	-1.32E-04	6.09E-06
1376.67810	-11.	5	1	5	4	2	2	3.58E-04	7.	3.56E-04	.7	-1.87E-02	-1.72E-04	2.16E-05
1377.38518	12.	5	2	4	4	3	1	2.73E-04	7.	2.87E-04	-5.0	-1.69E-02	-9.64E-05	5.05E-05

table 9 continued

observed position	o-c	upper			lower			observed strength	#s	computed strength	(o-c)‡	Z1 ^a	Z2 ^a	Z3 ^a
		J	K _a	K _c	J	K _a	K _c							
1377.78821	-13.	6	3	3	5	4	2	1.08E-04	5.	1.10E-04	-2.0	-1.04E-02	-2.75E-05	-2.77E-05
1379.61373	-16.	5	3	3	6	2	4	9.31E-05	12.	8.96E-05	3.8	-9.43E-03	-4.04E-05	8.92E-06
1386.12105	0.	2	2	1	3	1	2	2.56E-04	16.	2.20E-04	14.2	-1.47E-02	-1.28E-04	5.87E-06
1388.32854	-9.	5	2	3	4	3	2	3.09E-04	4.	3.08E-04	.3	-1.74E-02	-1.08E-04	-4.07E-05
1390.11040	19.	6	2	5	5	3	2	4.07E-04	4.	3.27E-04	19.7	-1.70E-02	-9.84E-05	-9.78E-04
1391.99683	-19.	7	3	5	6	4	2	1.23E-04	5.	1.18E-04	3.8	-1.08E-02	-3.18E-05	-2.95E-05
1392.27267	-8.	4	2	2	5	1	5	1.01E-04	3.	1.16E-04	-14.5	-1.07E-02	-8.26E-05	7.67E-06
1392.84027	-9.	5	2	3	6	1	6	6.89E-05	8.	5.89E-05	14.5	-7.63E-03	-5.51E-05	6.90E-06
1392.86612	19.	8	4	5	7	5	2	3.73E-05	6.	3.27E-05	12.3	-5.70E-03	-4.12E-06	-1.33E-05
1393.14457	-7.	2	0	2	1	1	1	1.60E-03	1.	1.63E-03	-1.7	-3.97E-02	-5.64E-04	-1.80E-05
1396.17635	5.	3	2	1	4	1	4	1.48E-04	9.	1.60E-04	-8.0	-1.26E-02	-7.83E-05	6.82E-06
1396.70095	-8.	7	3	4	6	4	3	1.07E-04	8.	1.19E-04	-10.9	-1.08E-02	-3.21E-05	-4.29E-05
1400.74635	5.	7	2	6	6	3	3	2.47E-04	7.	2.43E-04	1.8	-1.56E-02	-9.26E-05	7.44E-05
1401.11434	2.	4	3	2	5	2	3	8.39E-05	5.	8.49E-05	-1.1	-9.17E-03	-4.81E-05	6.71E-06
1403.75774	8.	2	1	1	2	0	2	4.17E-03	2.	4.27E-03	-2.5	-6.46E-02	-7.97E-04	1.38E-06
1405.03501	20.	4	1	3	3	2	2	9.80E-04	2.	8.96E-04	8.6	-2.96E-02	-3.07E-04	-2.92E-05
1407.68203	-4.	8	3	6	7	4	3	9.38E-05	7.	9.81E-05	-4.6	-9.83E-03	-3.12E-05	-3.83E-05
1408.25768	-3.	8	2	7	7	3	4	1.44E-04	8.	1.55E-04	-7.7	-1.24E-02	-7.73E-05	3.35E-05
1409.62671	2.	3	1	2	3	0	3	3.92E-03	2.	4.07E-03	-3.8	-6.30E-02	-7.96E-04	3.61E-06
1409.85929	0.	9	4	6	8	5	3	2.51E-05	11.	2.60E-05	-3.5	-5.08E-03	-5.30E-06	-1.20E-05
1410.32738	-1.	3	0	3	2	1	2	3.17E-03	2.	3.23E-03	-1.8	-5.59E-02	-8.35E-04	-3.41E-05
1410.73877	-37.	10	2	9	9	3	6	3.42E-05	12.	3.47E-05	-1.6	-5.87E-03	-3.39E-05	5.56E-06
1411.79808	15.	9	2	8	8	3	5	7.52E-05	2.	8.05E-05	-7.1	-8.93E-03	-5.49E-05	1.39E-05
1412.02260	-5.	4	3	1	5	2	4	8.40E-05	5.	7.52E-05	10.5	-8.63E-03	-4.52E-05	6.73E-06
1412.72979	0.	1	1	1	0	0	0	2.42E-03	3.	2.48E-03	-2.6	4.92E-02	6.22E-04	6.47E-06
1417.40900	-5.	8	3	5	7	4	4	9.75E-05	4.	9.96E-05	-2.1	-9.91E-03	-3.69E-05	-2.80E-05
1418.37387	3.	4	1	3	4	0	4	3.05E-03	2.	3.14E-03	-2.9	-5.53E-02	-7.23E-04	6.37E-06
1420.84465	0.	3	3	1	4	2	2	5.45E-05	6.	5.30E-05	2.8	-7.24E-03	-4.25E-05	4.32E-06
1425.28617	4.	2	1	2	1	0	1	3.56E-03	2.	3.62E-03	-1.5	5.93E-02	7.81E-04	1.50E-05
1426.85659	-22.	5	1	4	4	2	3	1.12E-03	6.	1.20E-03	-7.0	-3.42E-02	-3.82E-04	-3.70E-05
1427.30696	-9.	4	0	4	3	1	3	4.33E-03	1.	4.47E-03	-3.2	-6.58E-02	-9.80E-04	-5.17E-05
1430.25047	-13.	5	1	4	5	0	5	2.02E-03	1.	2.06E-03	-2.2	-4.48E-02	-6.14E-04	9.27E-06
1432.72098	2.	4	2	2	4	1	3	2.54E-03	2.	2.53E-03	.3	-4.98E-02	-5.31E-04	9.26E-06
1434.51409	4.	7	2	5	6	3	4	3.13E-04	7.	3.36E-04	-7.4	-1.82E-02	-1.40E-04	-3.19E-05
1434.58410	-4.	3	2	1	3	1	2	2.17E-03	2.	2.20E-03	-1.5	-4.66E-02	-3.67E-04	1.12E-05
1435.49297	10.	10	3	8	9	4	5	4.24E-05	11.	3.94E-05	7.1	-6.23E-03	-2.43E-05	-2.17E-05
1437.20193	0.	2	2	0	2	1	1	1.36E-03	6.	1.41E-03	-3.7	-3.71E-02	-4.01E-04	3.75E-06
1439.34520	-1.	5	4	2	6	3	3	1.75E-05	5.	1.69E-05	3.3	-4.11E-03	-7.02E-06	3.99E-06
1440.25999	6.	9	3	6	8	4	5	6.82E-05	5.	7.08E-05	-3.7	-8.35E-03	-3.70E-05	-2.00E-05
1441.02941	2.	7	2	5	7	1	6	1.07E-03	3.	1.12E-03	-4.2	-3.30E-02	-3.90E-04	1.03E-05
1441.46476	-12.	5	4	1	6	3	4	1.88E-05	3.	1.67E-05	11.0	-4.09E-03	-6.78E-06	4.01E-06
1443.49788	-18.	5	0	5	4	1	4	5.53E-03	1.	5.06E-03	8.5	-7.00E-02	-1.05E-03	-6.96E-05
1444.99354	-1.	6	1	5	6	0	6	1.16E-03	3.	1.22E-03	-5.5	-3.45E-02	-4.99E-04	1.20E-05
1445.54590	-3.	2	2	1	2	1	2	1.14E-03	2.	1.13E-03	.5	-3.33E-02	-3.69E-04	4.28E-06
1446.77924	7.	4	1	4	3	0	3	4.96E-03	1.	5.18E-03	-4.5	7.10E-02	9.68E-04	1.96E-05
1449.00959	1.	6	1	5	5	2	4	1.28E-03	2.	1.29E-03	-1.1	-3.55E-02	-4.28E-04	-4.28E-05
PR1450.21318	-9.	3	2	2	3	1	3	1.48E-03	2.	1.48E-03	-.3	-3.82E-02	-3.16E-04	-3.16E-06
1450.45721	1.	8	2	6	8	1	7	5.74E-04	3.	6.02E-04	-4.9	-2.42E-02	-2.99E-04	1.07E-05
1456.80559	5.	5	1	5	4	0	4	4.46E-03	8.	5.37E-03	-20.5	7.22E-02	1.05E-03	7.08E-05
1458.63239	6.	6	0	6	5	1	5	4.69E-03	1.	4.92E-03	-4.9	-6.90E-02	-1.06E-03	-8.63E-05
1463.49930	-8.	9	2	7	9	1	8	2.61E-04	6.	2.87E-04	-9.9	-1.67E-02	-2.17E-04	1.08E-05
1464.41334	9.	5	2	4	5	1	5	1.12E-03	2.	1.16E-03	-3.3	-3.36E-02	-4.12E-04	5.77E-06
1465.28846	-19.	10	3	7	9	4	6	3.82E-05	6.	4.43E-05	-15.9	-6.60E-03	-3.46E-05	-1.49E-05
1466.56921	-6.	9	3	6	9	2	7	2.32E-04	3.	2.40E-04	-3.3	-1.53E-02	-1.57E-04	8.69E-06
1467.06261	-14.	6	1	6	5	0	5	4.81E-03	1.	5.04E-03	-4.8	6.99E-02	1.06E-03	8.53E-05
1467.93261	-3.	8	3	5	8	2	6	3.79E-04	4.	3.97E-04	-4.8	-1.97E-02	-1.93E-04	1.01E-05
1468.36564	0.	10	3	7	10	2	8	1.17E-04	5.	1.24E-04	-6.4	-1.10E-02	-1.19E-04	7.40E-06
1470.85112	0.	2	2	1	1	1	0	2.52E-03	2.	2.55E-03	-1.2	4.99E-02	5.85E-04	5.84E-06
1470.89918	3.	7	1	6	6	2	5	1.22E-03	2.	1.21E-03	.5	-3.44E-02	-4.40E-04	-4.67E-05
1471.49513	11.	7	3	4	7	2	5	5.31E-04	13.	5.75E-04	-8.4	-2.38E-02	-2.10E-04	1.17E-05
PR1473.80252	19.	6	2	5	6	1	6	6.69E-04	4.	7.73E-04	-15.5	-2.77E-02	-3.48E-04	2.26E-04
1473.95777	18.	11	3	8	11	2	9	5.24E-05	4.	5.60E-05	-7.0	-7.41E-03	-8.32E-05	6.23E-06
1476.07507	8.	6	3	3	6	2	4	7.51E-04	3.	7.44E-04	.9	-2.71E-02	-2.35E-04	9.70E-06
1477.78828	0.	7	1	7	6	0	6	4.13E-03	2.	4.29E-03	-3.8	6.43E-02	1.02E-03	9.88E-05
1479.68212	0.	10	2	8	10	1	9	1.14E-04	3.	1.25E-04	-9.8	-1.10E-02	-1.51E-04	1.04E-05
1479.82308	-10.	8	1	7	8	0	8	3.30E-04	5.	3.64E-04	-10.3	-1.88E-02	-3.04E-04	1.58E-05

table 9 continued

observed position	o-c	upper			lower			observed strength	#s	computed strength	(o-c) #	Z1 ^a	Z2 ^a	Z3 ^a
		J	K _a	K _c	J	K _a	K _c							
1480.49015	-4.	5	3	2	5	2	3	7.98E-04	8.	8.54E-04	-7.1	-2.90E-02	-2.17E-04	6.54E-06
1483.62646	18.	12	3	9	12	2	10	2.39E-05	4.	2.20E-05	8.1	-4.64E-03	-5.47E-05	5.17E-06
1484.70167	-1.	7	2	6	7	1	7	4.91E-04	2.	5.30E-04	-7.8	-2.27E-02	-3.03E-04	7.61E-06
1485.70483	16.	9	2	7	8	3	6	1.99E-04	6.	2.00E-04	-7.	-1.40E-02	-1.34E-04	-2.53E-05
1485.93397	-39.	3	3	0	3	2	1	6.19E-04	3.	6.11E-04	1.3	-2.45E-02	-2.08E-04	5.71E-06
1486.06917	8.	8	0	8	7	1	7	3.16E-03	3.	3.31E-03	-4.8	-5.65E-02	-9.48E-04	-1.10E-04
1487.63293	-2.	3	3	1	3	2	2	6.08E-04	4.	6.05E-04	.5	-2.44E-02	-2.07E-04	5.81E-06
1488.66848	4.	4	3	2	4	2	3	8.23E-04	2.	8.16E-04	.8	-2.83E-02	-2.44E-04	7.63E-06
1488.94660	0.	8	1	8	7	0	7	3.09E-03	4.	3.33E-03	-7.8	5.67E-02	9.48E-04	1.09E-04
1490.55587	-16.	5	3	3	5	2	4	7.89E-04	8.	7.87E-04	.2	-2.78E-02	-2.24E-04	8.03E-06
1491.90603	-14.	8	1	7	7	2	6	1.01E-03	2.	1.01E-03	.3	-3.13E-02	-4.17E-04	-4.85E-05
PR1493.62542	0.	6	3	4	6	2	5	5.22E-04	2.	5.53E-04	-6.0	-2.31E-02	-2.20E-04	-1.68E-04
1494.00902	0.	3	2	1	2	1	2	1.91E-03	1.	1.90E-03	.3	4.32E-02	3.90E-04	8.20E-07
1494.91096	-2.	4	2	3	3	1	2	2.38E-03	2.	2.40E-03	-7.	4.84E-02	5.67E-04	2.71E-05
1496.76676	-4.	8	2	7	8	1	8	2.85E-04	2.	3.13E-04	-9.7	-1.74E-02	-2.59E-04	1.22E-05
1497.95587	0.	7	3	5	7	2	6	3.77E-04	7.	4.44E-04	-17.8	-2.09E-02	-2.04E-04	1.22E-05
1497.99658	25.	9	1	8	9	0	9	1.60E-04	16.	1.87E-04	-16.7	-1.35E-02	-2.30E-04	1.66E-05
1498.10332	-10.	11	2	9	11	1	10	4.37E-05	9.	5.07E-05	-16.0	-7.03E-03	-1.01E-04	9.69E-06
1500.38653	9.	9	1	9	8	0	8	2.21E-03	4.	2.37E-03	-7.3	4.77E-02	8.44E-04	1.14E-04
1504.86143	-3.	5	2	4	4	1	3	2.24E-03	2.	2.17E-03	3.3	4.59E-02	5.69E-04	3.51E-05
1511.08946	-4.	10	0	10	9	1	9	1.47E-03	2.	1.56E-03	-5.8	-3.86E-02	-7.25E-04	-1.13E-04
1511.72010	0.	10	2	8	9	3	7	1.51E-04	11.	1.34E-04	11.1	-1.14E-02	-1.21E-04	-2.21E-05
1511.95610	3.	10	1	10	9	0	9	1.50E-03	3.	1.56E-03	-3.7	3.86E-02	7.24E-04	1.13E-04
1515.75818	5.	10	1	9	10	0	10	7.58E-05	15.	9.25E-05	-22.1	-9.47E-03	-1.70E-04	1.67E-05
1517.17290	-1.	4	2	2	3	1	3	1.32E-03	4.	1.35E-03	-2.6	3.63E-02	4.58E-04	7.37E-06
1520.36390	-11.	10	3	8	10	2	9	7.37E-05	4.	7.92E-05	-7.4	-8.80E-03	-1.06E-04	1.20E-05
1521.70597	2.	7	2	6	6	1	5	1.48E-03	1.	1.48E-03	.0	3.79E-02	4.63E-04	5.80E-05
1523.08018	-3.	11	0	11	10	1	10	8.79E-04	4.	9.49E-04	-8.0	-3.01E-02	-6.01E-04	-1.08E-04
1523.54369	-10.	11	1	11	10	0	10	9.76E-04	5.	9.50E-04	2.6	3.01E-02	6.01E-04	1.08E-04
1531.29218	16.	7	4	3	7	3	4	1.93E-04	4.	1.97E-04	-2.0	-1.40E-02	-7.54E-05	8.47E-06
1533.89150	36.	3	3	1	2	2	0	2.12E-03	9.	2.17E-03	-2.4	4.62E-02	4.44E-04	4.86E-06
1534.83341	-2.	12	0	12	11	1	11	4.98E-04	3.	5.39E-04	-8.1	-2.26E-02	-4.82E-04	-9.81E-05
1534.92497	-38.	5	4	1	5	3	2	2.34E-04	6.	2.77E-04	-18.2	-1.66E-02	-8.79E-05	7.44E-06
1535.64008	-1.	5	4	2	5	3	3	2.55E-04	5.	2.76E-04	-8.1	-1.65E-02	-8.79E-05	7.48E-06
1535.66932	-34.	4	4	1	4	3	2	1.80E-04	10.	2.15E-04	-19.6	-1.46E-02	-8.47E-05	5.64E-06
1535.70827	-35.	6	4	3	6	3	4	2.90E-04	12.	2.53E-04	12.8	-1.58E-02	-9.74E-05	8.41E-06
1536.88257	-20.	8	4	5	8	3	6	1.29E-04	18.	1.31E-04	-1.2	-1.14E-02	-7.60E-05	8.96E-06
1537.12537	6.	11	2	9	10	3	8	8.30E-05	2.	8.15E-05	1.8	-8.91E-03	-1.04E-04	-1.89E-05
1538.50768	25.	9	4	6	9	3	7	8.00E-05	16.	7.83E-05	2.1	-8.79E-03	-6.78E-05	8.70E-06
1541.18951	2.	10	4	7	10	3	8	3.87E-05	5.	4.24E-05	-9.6	-6.47E-03	-5.55E-05	8.06E-06
1542.49555	39.	12	3	10	12	2	11	1.81E-05	10.	1.61E-05	11.1	-3.96E-03	-5.59E-05	7.62E-06
1544.32619	-10.	5	2	3	4	1	4	8.70E-04	2.	8.12E-04	6.7	2.81E-02	3.82E-04	8.56E-06
1546.01308	13.	11	1	10	10	2	9	3.02E-04	5.	2.96E-04	1.8	-1.69E-02	-2.35E-04	-4.12E-05
1546.39034	-16.	13	0	13	12	1	12	3.27E-04	8.	2.85E-04	12.7	-1.64E-02	-3.74E-04	-8.58E-05
1548.78609	3.	4	3	2	3	2	1	1.81E-03	1.	1.82E-03	-.3	4.22E-02	4.15E-04	9.85E-06
1550.68115	3.	4	3	1	3	2	2	1.76E-03	2.	1.80E-03	-2.0	4.20E-02	4.14E-04	9.62E-06
1552.31401	-22.	12	2	11	12	1	12	1.82E-05	4.	1.94E-05	-6.7	-4.34E-03	-8.55E-05	1.44E-05
1556.90033	-26.	11	2	10	10	1	9	2.94E-04	3.	2.99E-04	-1.9	1.70E-02	2.34E-04	4.15E-05
1562.42620	0.	5	3	3	4	2	2	1.41E-03	2.	1.42E-03	-.5	3.73E-02	3.44E-04	1.62E-05
1567.85756	3.	12	2	11	11	1	10	1.64E-04	5.	1.63E-04	.4	1.26E-02	1.78E-04	3.58E-05
1568.04423	-8.	5	3	2	4	2	3	1.37E-03	3.	1.35E-03	1.1	3.65E-02	3.19E-04	1.60E-05
PR1574.37584	0.	6	3	4	5	2	3	8.46E-04	3.	8.27E-04	2.3	2.85E-02	3.16E-04	-1.08E-04
1575.57418	-4.	13	1	12	12	2	11	7.51E-05	4.	8.22E-05	-9.4	-8.91E-03	-1.31E-04	-2.96E-05
1580.12283	16.	10	5	5	10	4	6	1.53E-05	2.	1.47E-05	3.7	-3.82E-03	-2.32E-05	5.22E-06
1584.31698	12.	7	3	5	6	2	4	7.05E-04	2.	7.09E-04	-.5	2.63E-02	2.81E-04	1.34E-05
1584.87785	-10.	8	5	4	8	4	5	4.13E-05	6.	4.10E-05	.8	-6.38E-03	-2.88E-05	6.37E-06
1584.98926	-11.	7	5	2	7	4	3	5.73E-05	6.	5.72E-05	.1	-7.54E-03	-2.90E-05	6.40E-06
1585.25026	0.	7	5	3	7	4	4	5.84E-05	7.	5.72E-05	2.0	-7.54E-03	-2.89E-05	6.41E-06
1587.01714	1.	6	3	3	5	2	4	9.26E-04	1.	9.26E-04	-.1	3.01E-02	3.11E-04	1.08E-05
1589.24462	0.	14	1	13	13	2	12	4.74E-05	14.	3.84E-05	18.9	-6.08E-03	-9.30E-05	-2.35E-05
1591.50039	4.	14	2	13	13	1	12	3.93E-05	8.	3.85E-05	2.0	6.09E-03	9.29E-05	2.35E-05
1592.54093	-2.	8	3	6	7	2	5	4.62E-04	2.	4.59E-04	.6	2.12E-02	2.25E-04	1.14E-05
1598.31952	-27.	4	4	1	3	3	0	1.20E-03	3.	1.22E-03	-1.4	3.46E-02	2.47E-04	3.39E-06
1598.34784	13.	4	4	0	3	3	1	1.19E-03	2.	1.22E-03	-2.3	3.46E-02	2.47E-04	3.39E-06
1605.22401	1.	10	3	8	9	2	7	1.70E-04	4.	1.66E-04	2.3	1.27E-02	1.45E-04	1.26E-05
1608.40130	1.	7	3	4	6	2	5	5.47E-04	2.	5.54E-04	-1.3	2.33E-02	2.46E-04	7.67E-06

table 9 continued

observed position	o-c	upper				lower				observed strength	ts	computed strength	(o-c)%	z1 ^a	z2 ^a	z3 ^a
		J	K _a	K _c	J	K _a	K _c									
1610.72299	-18.	11	3	9	10	2	8		8.42E-05	4.	9.27E-05	-10.1	9.50E-03	1.11E-04	1.48E-05	
1611.66657	-7.	7	2	5	6	1	6		1.91E-04	6.	1.98E-04	-3.6	1.39E-02	2.07E-04	6.20E-06	
1613.90687	6.	5	4	2	4	3	1		9.25E-04	2.	9.37E-04	-1.2	3.04E-02	1.99E-04	6.34E-06	
1614.10578	4.	5	4	1	4	3	2		9.21E-04	2.	9.36E-04	-1.6	3.04E-02	1.99E-04	6.32E-06	
1616.33165	-20.	12	3	10	11	2	9		4.29E-05	11.	4.86E-05	-13.4	6.88E-03	8.11E-05	1.63E-05	
1622.95524	0.	13	3	11	12	2	10		2.22E-05	8.	2.39E-05	-7.6	4.82E-03	5.62E-05	1.47E-05	
1629.16897	-12.	6	4	3	5	3	2		6.64E-04	2.	6.71E-04	-1.1	2.57E-02	1.94E-04	8.88E-06	
1629.96040	-29.	6	4	2	5	3	3		6.61E-04	2.	6.71E-04	-1.5	2.57E-02	2.07E-04	7.58E-06	
1633.09228	4.	8	3	5	7	2	6		2.80E-04	4.	2.89E-04	-3.2	1.68E-02	1.99E-04	8.14E-06	
1642.55350	-3.	5	3	3	4	0	4		2.53E-05	5.	2.65E-05	-4.8	-5.10E-03	-4.81E-05	-9.14E-07	
1643.73466	0.	7	4	4	6	3	3		4.40E-04	1.	4.43E-04	-.7	2.09E-02	1.39E-04	7.82E-06	
1646.07015	-7.	7	4	3	6	3	4		4.00E-04	3.	4.40E-04	-10.0	2.08E-02	1.36E-04	7.11E-06	
1651.40692	35.	8	2	6	7	1	7		8.55E-05	10.	8.70E-05	-1.8	9.18E-03	1.42E-04	4.42E-06	
1657.10492	0.	8	4	5	7	3	4		2.61E-04	5.	2.70E-04	-3.6	1.63E-02	1.29E-04	7.65E-06	
*1663.85074	-74.	5	5	0	4	1	9.	42E-04	4.	9.46E-04	-.4	3.06E-02	1.41E-04	2.74E-06		
1668.73529	3.	9	4	6	8	3	5		1.51E-04	7.	1.51E-04	.1	1.22E-02	1.09E-04	7.15E-06	
1685.59287	-16.	11	4	8	10	3	7		4.17E-05	14.	3.80E-05	8.8	6.10E-03	6.18E-05	5.26E-06	
1694.43616	25.	9	2	7	8	1	8		3.32E-05	10.	3.68E-05	-10.7	5.97E-03	9.38E-05	2.86E-06	
1694.97484	24.	7	5	3	6	4	2		2.13E-04	6.	2.24E-04	-4.9	1.49E-02	8.07E-05	4.57E-06	
1695.05410	-16.	7	5	2	6	4	3		2.11E-04	8.	2.24E-04	-5.9	1.49E-02	8.07E-05	4.57E-06	
1710.27485	31.	8	5	4	7	4	3		1.43E-04	15.	1.37E-04	4.4	1.16E-02	7.09E-05	5.01E-06	
1710.56218	-10.	8	5	3	7	4	4		1.27E-04	4.	1.37E-04	-7.7	1.16E-02	7.09E-05	5.00E-06	
1720.39685	-27.	8	3	6	7	0	7		2.08E-05	15.	2.60E-05	-24.9	-5.04E-03	-5.72E-05	-5.08E-07	
1726.03699	-3.	9	5	4	8	4	5		7.67E-05	10.	7.66E-05	.1	8.69E-03	5.92E-05	4.84E-06	
*1729.57598	20.	6	6	1	5	5	0		2.59E-04	3.	2.62E-04	-1.2	1.62E-02	3.19E-05	1.24E-06	
*1745.09734	56.	7	6	2	6	5	1		1.87E-04	3.	1.72E-04	8.0	1.31E-02	3.46E-05	2.14E-06	
*1810.07599	82.	8	7	2	7	6	1		3.22E-05	6.	3.08E-05	4.4	5.55E-03	-1.89E-06	6.55E-07	

a. the computed strength = $(Z1 + Z2 + Z3)^2$ where Z1 is the contribution due to no interactions while Z2 and Z3 are due to Fermi and Coriolis-type interactions, respectively.

positions in cm⁻¹

o-c, observed minus computed line positions $\times 10^5$. The computed values are derived from the energy levels given in Table 2

ts are the estimated uncertainties in the measured line strengths in percent.

(o-c)%, observed minus computed line strength values given in percent. Computed value are derived from constants obtained in this work and given in Table 5.

*asterisks denote doubled absorptions with the quantum assignment given for one of the transitions.

The strength given represents the sum of the strengths of the two comparable transitions.

PR indicates that the transition involves strong Coriolis coupling with a level in the (100) state. Strengths normalized to 99.9% HD¹⁶O.

Table 10. Line positions and strengths ($\text{cm}^{-2}/\text{atm.}$ at 296K) of the A-type transitions of the (020)-(010) band of HD^{16}O .

observed position	o-c	upper J	K _a	K _c	lower J	K _a	K _c	observed strength	#s	computed strength	(o-c)%	Z1 ^a	Z2 ^a	Z3 ^a
1192.22906	0.	13	1	13	14	1	14	2.18E-05	5.	2.29E-05	-4.9	4.92E-03	-1.22E-04	-1.42E-05
1204.74633	0.	12	1	11	13	1	12	3.08E-05	5.	2.74E-05	11.0	5.31E-03	-6.97E-05	-4.37E-06
1205.57980	-13.	12	1	12	13	1	13	5.83E-05	4.	5.14E-05	11.8	7.36E-03	-1.76E-04	-1.69E-05
1215.42259	-15.	10	2	8	11	2	9	8.53E-05	12.	7.65E-05	10.3	8.85E-03	-1.05E-04	-1.85E-06
1220.64926	-1.	11	3	9	12	3	10	3.78E-05	18.	3.63E-05	4.0	6.07E-03	-4.96E-05	-1.30E-06
1226.62100	5.	10	1	9	11	1	10	1.21E-04	4.	1.20E-04	.5	1.11E-02	-1.57E-04	-6.06E-06
1227.64866	6.	9	2	7	10	2	8	1.55E-04	6.	1.59E-04	-2.5	1.28E-02	-1.60E-04	-2.23E-06
1231.83627	0.	10	0	10	11	0	11	2.20E-04	4.	2.12E-04	3.9	1.49E-02	-3.35E-04	-2.17E-05
1233.77323	40.	10	3	8	11	3	9	6.14E-05	5.	7.62E-05	-24.1	8.80E-03	-7.13E-05	-1.76E-06
1241.23552	2.	8	2	6	9	2	7	3.21E-04	15.	3.05E-04	5.1	1.77E-02	-2.33E-04	-2.70E-06
1243.69426	0.	9	2	8	10	2	9	2.19E-04	6.	2.33E-04	-6.2	1.55E-02	-2.04E-04	-5.65E-06
1244.81238	0.	9	0	9	10	0	10	4.15E-04	5.	3.86E-04	7.1	2.01E-02	-4.42E-04	-2.32E-05
1245.25130	2.	9	1	9	10	1	10	4.20E-04	3.	3.87E-04	7.9	2.01E-02	-4.38E-04	-2.29E-05
1247.43772	23.	9	3	7	10	3	8	1.29E-04	6.	1.49E-04	-15.1	1.23E-02	-9.84E-05	-2.36E-06
1253.07384	-4.	8	3	5	9	3	6	2.22E-04	7.	2.37E-04	-6.6	1.55E-02	-1.37E-04	-1.79E-06
1256.06878	-2.	7	2	5	8	2	6	5.58E-04	2.	5.36E-04	4.0	2.35E-02	-3.22E-04	-3.33E-06
1256.55822	-1.	8	2	7	9	2	8	4.02E-04	2.	4.10E-04	-1.9	2.05E-02	-2.72E-04	-4.58E-06
1257.62304	-3.	8	0	8	9	0	9	6.79E-04	6.	6.52E-04	3.9	2.61E-02	-5.67E-04	-2.38E-05
1258.38452	7.	8	1	8	9	1	9	6.64E-04	3.	6.55E-04	1.4	2.62E-02	-5.60E-04	-2.34E-05
1259.26851	6.	7	1	6	8	1	7	7.20E-04	3.	6.84E-04	5.0	2.66E-02	-4.46E-04	-7.34E-06
1269.78113	0.	7	2	6	8	2	7	6.33E-04	1.	6.65E-04	-5.1	2.61E-02	-3.39E-04	-1.05E-06
1270.23413	5.	7	0	7	8	0	8	1.10E-03	2.	1.02E-03	7.0	3.27E-02	-7.10E-04	-2.35E-05
1270.79257	0.	7	3	4	8	3	5	3.74E-04	3.	4.04E-04	-8.1	2.03E-02	-1.66E-04	-3.08E-06
1271.50377	-3.	6	1	5	7	1	6	1.12E-03	3.	1.07E-03	4.4	3.33E-02	-5.91E-04	-7.19E-06
1271.51397	-11.	7	1	7	8	1	8	1.12E-03	5.	1.02E-03	8.6	3.27E-02	-6.94E-04	-2.27E-05
1276.24109	-8.	7	3	5	8	3	6	3.99E-04	2.	4.29E-04	-7.4	2.09E-02	-1.74E-04	-2.94E-06
1282.62912	-3.	6	0	6	7	0	7	1.56E-03	2.	1.49E-03	4.4	3.95E-02	-8.64E-04	-2.22E-05
1284.68298	-11.	6	1	6	7	1	7	1.68E-03	1.	1.49E-03	11.1	3.95E-02	-8.32E-04	-2.06E-05
1284.87533	12.	5	1	4	6	1	5	1.65E-03	5.	1.53E-03	7.2	3.99E-02	-7.46E-04	-6.69E-06
1288.22142	-3.	6	3	3	7	3	4	6.35E-04	9.	6.07E-04	4.5	2.48E-02	-2.09E-04	-2.77E-06
1288.76309	-2.	5	2	3	6	2	4	1.24E-03	2.	1.21E-03	2.1	3.54E-02	-5.13E-04	-5.71E-06
1291.20956	-7.	7	4	4	8	4	5	2.01E-04	8.	2.46E-04	-22.5	1.57E-02	-5.81E-05	-3.03E-09
PR1291.29490	0.	6	3	4	7	3	5	4.68E-04	2.	5.14E-04	-9.7	2.28E-02	-2.05E-04	6.24E-05
1294.86457	-6.	5	0	5	6	0	6	2.05E-03	3.	1.99E-03	3.1	4.56E-02	-1.02E-03	-1.97E-05
1297.46025	8.	5	2	4	6	2	5	1.32E-03	2.	1.32E-03	-.1	3.69E-02	-5.23E-04	1.08E-06
1297.94319	4.	5	1	5	6	1	6	2.05E-03	2.	1.97E-03	3.8	4.54E-02	-9.59E-04	-1.64E-05
1298.87703	1.	5	0	5	5	2	4	4.14E-05	8.	3.52E-05	14.9	-6.27E-03	3.49E-04	-1.60E-05
1299.31772	1.	4	1	3	5	1	4	2.10E-03	1.	1.97E-03	6.2	4.53E-02	-8.91E-04	-5.80E-06
1304.29867	14.	7	1	7	7	1	6	3.30E-05	3.	2.77E-05	15.9	5.59E-03	-3.44E-04	2.46E-05
1305.10319	13.	5	3	2	6	3	3	8.12E-04	3.	7.91E-04	2.6	2.83E-02	-2.15E-04	1.30E-06
1306.06977	-32.	4	2	2	5	2	3	1.64E-03	1.	1.49E-03	8.8	3.92E-02	-5.71E-04	-8.31E-06
1307.15197	-17.	4	0	4	5	0	5	2.52E-03	3.	2.43E-03	3.5	5.05E-02	-1.16E-03	-1.62E-05
PR1311.34137	0.	4	1	4	5	1	5	2.45E-03	1.	2.36E-03	3.6	4.97E-02	-1.02E-03	-8.40E-05
1314.63710	0.	3	1	2	4	1	3	2.33E-03	3.	2.22E-03	4.5	4.82E-02	-9.95E-04	-4.39E-06
1319.87102	-11.	3	0	3	4	0	4	2.80E-03	1.	2.69E-03	4.1	5.31E-02	-1.26E-03	-1.20E-05
1321.46568	4.	4	3	1	5	3	2	8.01E-04	6.	8.50E-04	-6.1	2.94E-02	-2.70E-04	-6.71E-07
1322.22051	13.	5	4	1	6	4	2	3.30E-04	6.	3.75E-04	-13.6	1.94E-02	-8.31E-05	-3.09E-07
1322.28164	-2.	5	4	2	6	4	3	3.11E-04	3.	3.75E-04	-20.5	1.94E-02	-8.31E-05	-3.14E-07
1323.42542	-1.	3	2	1	4	2	2	1.55E-03	3.	1.53E-03	1.1	3.96E-02	-4.46E-04	-1.85E-05
1324.94200	0.	3	1	3	4	1	4	2.62E-03	2.	2.53E-03	3.6	5.14E-02	-1.10E-03	-1.93E-05
1330.62181	4.	2	1	1	3	1	2	2.24E-03	5.	2.11E-03	5.6	4.70E-02	-1.02E-03	-2.40E-06
*1331.20129	-135.	7	6	1	8	6	2	8.41E-05	1.	7.88E-05	6.3	8.88E-03	-2.50E-06	5.18E-07
1333.38913	-18.	2	0	2	3	0	3	2.84E-03	2.	2.63E-03	7.6	5.25E-02	-1.29E-03	-7.58E-06
1337.59794	8.	3	3	1	4	3	2	6.15E-04	4.	6.48E-04	-5.4	2.57E-02	-2.50E-04	-1.03E-06
1338.73429	0.	2	1	2	3	1	3	2.33E-03	1.	2.28E-03	2.0	4.89E-02	-1.08E-03	-9.66E-06
1340.37579	35.	2	2	0	3	2	1	1.19E-03	3.	1.11E-03	6.5	3.39E-02	-5.45E-04	-1.35E-06
1341.75043	-21.	2	2	1	3	2	2	1.12E-03	4.	1.12E-03	-.3	3.41E-02	-5.46E-04	-1.87E-06
*1346.43479	-83.	6	6	0	7	6	1	6.60E-05	7.	6.78E-05	-2.7	8.23E-03	-1.75E-06	5.72E-07
1347.09300	1.	1	0	2	1	1	1	1.57E-03	2.	1.47E-03	6.3	3.92E-02	-8.87E-04	0.00E+00
1347.81510	1.	1	0	1	2	0	2	2.16E-03	2.	2.12E-03	2.0	4.72E-02	-1.20E-03	-3.35E-06
1352.70829	-8.	1	1	1	2	1	2	1.76E-03	3.	1.52E-03	13.8	3.99E-02	-9.10E-04	-3.51E-06
1362.96992	0.	0	0	0	1	0	1	1.19E-03	9.	1.18E-03	.4	3.54E-02	-9.34E-04	0.00E+00
PR1369.72533	25.	6	2	5	6	2	4	1.60E-04	7.	1.35E-04	15.9	1.24E-02	-4.16E-04	-3.94E-04
1372.12977	7.	2	1	2	2	1	1	7.70E-04	6.	7.22E-04	6.3	2.76E-02	-7.73E-04	-2.25E-06
1378.21056	-3.	5	2	4	5	2	3	3.66E-04	3.	3.27E-04	10.6	1.86E-02	-5.52E-04	4.30E-05
1383.75218	-9.	4	2	3	4	2	2	6.89E-04	6.	6.62E-04	4.0	2.63E-02	-6.51E-04	4.92E-05
PR1386.78217	-2.	3	2	2	3	2	1	1.35E-03	2.	1.27E-03	5.9	3.62E-02	-6.03E-04	7.27E-05
1388.00891	8.	2	2	1	2	2	0	2.39E-03	5.	2.37E-03	.8	4.97E-02	-1.02E-03	2.05E-06
1388.70948	0.	2	2	0	2	2	1	2.49E-03	2.	2.38E-03	4.4	4.98E-02	-1.02E-03	1.55E-06
1390.04664	-1.	2	1	1	2	1	2	7.75E-04	4.	7.51E-04	3.1	2.82E-02	-7.67E-04	-6.73E-06
1390.21375	2.	3	2	1	3	2	2	1.34E-03	3.	1.28E-03	4.4	3.65E-02	-6.05E-04	-7.65E-05
1393.62424	3.	4	2	2	4	2	3	7.24E-04	2.	6.77E-04	6.5	2.67E-02	-6.72E-04	-3.07E-05
1394.12551	1.	1	0	1	0	0	0	1.21E-03	3.	1.17E-03	3.3	3.52E-02	-1.01E-03	5.65E-06

table 10 continued

observed position	o-c	upper J K _a K _c	lower J K _a K _c	observed strength	%s	computed strength	(o-c) %	Z1 ^a	Z2 ^a	Z3 ^a
1396.46338	6.	7 3 5	7 3 4	1.53E-04	4.	1.35E-04	11.8	1.20E-02	-3.29E-04	-1.32E-05
PR1398.98861	-10.	6 3 4	6 3 3	2.62E-04	4.	2.52E-04	3.8	1.59E-02	-3.92E-04	3.97E-04
1399.08904	-1.	3 1 2	3 1 3	4.26E-04	5.	4.15E-04	2.7	2.10E-02	-6.28E-04	-1.16E-05
1399.70517	-8.	5 2 3	5 2 4	3.77E-04	1.	3.44E-04	8.8	1.91E-02	-5.67E-04	-2.20E-05
1399.99897	-5.	5 3 3	5 3 2	6.16E-04	3.	5.95E-04	3.4	2.48E-02	-4.51E-04	2.03E-05
1400.28862	-17.	4 3 2	4 3 1	1.01E-03	10.	1.11E-03	-10.0	3.39E-02	-5.87E-04	6.31E-06
1401.39793	-1.	5 3 2	5 3 3	6.32E-04	3.	5.99E-04	5.2	2.49E-02	-4.27E-04	2.40E-05
1402.99970	5.	6 3 3	6 3 4	3.29E-04	1.	2.98E-04	9.3	1.77E-02	-4.01E-04	-1.48E-05
1406.07081	4.	7 3 4	7 3 5	1.56E-04	5.	1.40E-04	10.4	1.22E-02	-3.18E-04	-2.38E-05
1408.89001	34.	6 2 4	6 2 5	2.08E-04	6.	1.65E-04	20.4	1.33E-02	-4.59E-04	-1.82E-05
1409.02726	0.	2 1 2	1 1 1	1.50E-03	3.	1.45E-03	3.3	3.91E-02	-1.06E-03	2.14E-05
1409.40356	5.	2 0 2	1 0 1	2.10E-03	2.	2.05E-03	2.2	4.67E-02	-1.38E-03	1.26E-05
1410.99740	2.	4 1 3	4 1 4	2.53E-04	4.	2.36E-04	6.8	1.59E-02	-5.34E-04	-1.52E-05
1415.35208	24.	2 1 1	1 1 0	1.58E-03	3.	1.43E-03	9.4	3.89E-02	-1.02E-03	1.06E-05
1415.76035	-10.	9 4 6	9 4 5	3.21E-05	3.	3.21E-05	.0	5.81E-03	-1.44E-04	-5.92E-06
*1415.98848	133.	4 4 1	4 4 0	2.55E-03	3.	2.37E-03	7.2	4.92E-02	-5.47E-04	6.57E-07
1416.25348	-9.	5 4 1	5 4 2	6.38E-04	3.	6.49E-04	-1.7	2.58E-02	-2.94E-04	1.51E-06
1416.46398	-14.	6 4 3	6 4 2	3.44E-04	3.	3.38E-04	1.8	1.87E-02	-2.76E-04	3.45E-06
1417.10143	5.	7 4 3	7 4 4	1.89E-04	9.	1.67E-04	11.7	1.31E-02	-1.89E-04	-8.93E-06
1417.91710	0.	8 4 4	8 4 5	7.98E-05	29.	7.62E-05	4.5	8.92E-03	-1.77E-04	-6.88E-06
1422.77477	5.	3 1 3	2 1 2	2.14E-03	0.	2.11E-03	1.4	4.72E-02	-1.35E-03	5.64E-05
1424.03846	6.	3 0 3	2 0 2	2.56E-03	1.	2.49E-03	2.7	5.15E-02	-1.58E-03	2.18E-05
1425.50528	-7.	5 1 4	5 1 5	1.35E-04	9.	1.32E-04	2.4	1.20E-02	-4.59E-04	-1.76E-05
1432.48447	1.	3 1 2	2 1 1	2.08E-03	2.	2.04E-03	2.1	4.64E-02	-1.27E-03	1.58E-05
*1434.56378	1.	5 5 0	5 5 1	1.00E-03	0.	1.01E-03	-1.3	3.21E-02	-2.61E-04	8.75E-08
PR1435.11612	-11.	3 2 2	2 2 1	1.08E-03	3.	1.04E-03	3.7	3.29E-02	-4.98E-04	-1.49E-04
1435.60292	2.	8 5 3	8 5 4	6.12E-05	16.	6.67E-05	-8.9	8.28E-03	-1.17E-04	2.37E-08
1436.05352	31.	9 5 4	9 5 5	2.62E-05	12.	2.99E-05	-14.3	5.57E-03	-9.53E-05	-3.26E-07
PR1436.24156	3.	4 1 4	3 1 3	2.26E-03	4.	2.28E-03	-.9	4.89E-02	-1.46E-03	3.29E-04
1437.84470	1.	4 0 4	3 0 3	2.56E-03	2.	2.49E-03	2.9	5.15E-02	-1.66E-03	3.32E-05
1442.14114	9.	6 1 5	6 1 6	8.22E-05	3.	7.21E-05	12.2	8.91E-03	-3.97E-04	-1.93E-05
1449.40520	-2.	4 1 3	3 1 2	2.16E-03	2.	2.10E-03	2.9	4.71E-02	-1.33E-03	2.01E-05
1449.42904	-4.	5 1 5	4 1 4	2.16E-03	2.	2.04E-03	5.5	4.67E-02	-1.54E-03	2.87E-05
1450.54056	-1.	4 2 3	3 2 2	1.46E-03	2.	1.40E-03	4.5	3.82E-02	-7.96E-04	-6.38E-05
1450.87461	9.	5 0 5	4 0 4	2.23E-03	2.	2.16E-03	3.2	4.81E-02	-1.65E-03	4.64E-05
1453.74180	-3.	4 2 2	3 2 1	1.40E-03	3.	1.40E-03	-.2	3.82E-02	-8.13E-04	5.78E-05
*1455.10738	23.	6 6 1	6 6 0	3.20E-04	6.	3.36E-04	-5.0	1.84E-02	-1.10E-04	-1.53E-07
*1455.45466	-9.	7 6 2	7 6 1	1.68E-04	3.	1.77E-04	-5.5	1.34E-02	-1.02E-04	-3.49E-07
*1455.83632	-4.	8 6 3	8 6 2	8.19E-05	12.	8.85E-05	-8.1	9.50E-03	-8.99E-05	-1.67E-07
1460.21778	-4.	7 1 6	7 1 7	4.17E-05	4.	3.78E-05	9.3	6.51E-03	-3.41E-04	-2.02E-05
1462.31736	-14.	6 1 6	5 1 5	1.70E-03	2.	1.63E-03	4.1	4.18E-02	-1.50E-03	5.14E-05
1463.15167	2.	4 3 2	3 3 1	5.68E-04	2.	5.50E-04	3.1	2.38E-02	-3.41E-04	-1.05E-05
1463.29609	-7.	4 3 1	3 3 0	5.76E-04	2.	5.50E-04	4.4	2.38E-02	-3.41E-04	-1.10E-05
1463.87960	0.	4 2 3	4 0 4	4.99E-05	3.	5.66E-05	-13.4	-7.73E-03	1.99E-04	6.07E-06
1465.76481	10.	5 2 4	4 2 3	4.14E-03	2.	4.35E-03	4.0	3.77E-02	-8.62E-04	-3.82E-05
1465.95343	-13.	5 1 4	4 1 3	1.85E-03	4.	1.81E-03	2.1	4.38E-02	-1.28E-03	2.40E-05
1469.15853	3.	5 2 4	5 0 5	4.82E-05	7.	5.84E-05	-21.2	-7.90E-03	2.48E-04	8.72E-06
1471.57544	2.	5 2 3	4 2 2	1.36E-03	2.	1.34E-03	1.5	3.74E-02	-8.61E-04	3.87E-05
1474.93585	7.	7 1 7	6 1 6	1.26E-03	3.	1.17E-03	7.3	3.55E-02	-1.40E-03	6.84E-05
PR1476.65464	-19.	6 2 5	6 0 6	4.24E-05	20.	4.06E-05	4.2	-6.94E-03	2.50E-04	3.11E-04
*1476.87069	0.	7 7 0	7 7 1	9.02E-05	4.	8.89E-05	1.4	9.47E-03	-4.10E-05	-1.89E-07
*1477.65950	0.	9 7 2	9 7 3	2.22E-05	22.	2.30E-05	-3.4	4.83E-03	-3.54E-05	-3.38E-07
1478.92234	-37.	8 1 7	8 1 8	2.04E-05	5.	1.88E-05	7.7	4.65E-03	-2.88E-04	-2.03E-05
1479.17968	27.	5 3 3	4 3 2	6.93E-04	4.	6.97E-04	-.5	2.68E-02	-3.66E-04	-3.51E-05
1479.66461	-5.	5 3 2	4 3 1	7.27E-04	3.	6.97E-04	4.1	2.68E-02	-3.46E-04	-4.44E-05
PR1480.66739	17.	6 2 5	5 2 4	1.03E-03	3.	1.11E-03	-7.8	3.32E-02	-7.79E-04	9.35E-04
1481.94758	27.	6 1 5	5 1 4	1.50E-03	12.	1.37E-03	8.9	3.81E-02	-1.14E-03	2.74E-05
1487.31567	30.	8 1 8	7 1 7	7.85E-04	3.	7.61E-04	3.0	2.88E-02	-1.24E-03	8.14E-05
1487.70031	-1.	8 0 8	7 0 7	8.45E-04	3.	7.68E-04	9.1	2.89E-02	-1.26E-03	8.43E-05
1489.64014	5.	6 2 4	5 2 3	1.10E-03	2.	1.07E-03	2.9	3.35E-02	-8.15E-04	3.00E-05
1494.41193	5.	5 4 2	4 4 1	2.44E-04	3.	2.20E-04	9.7	1.50E-02	-1.22E-04	-1.95E-06
1494.42321	-2.	5 4 1	4 4 0	2.40E-04	3.	2.20E-04	8.2	1.50E-02	-1.22E-04	-1.97E-06
PR1495.28360	1.	6 3 4	5 3 3	5.25E-04	5.	4.71E-04	10.4	2.30E-02	-3.89E-04	-8.96E-04
1495.38300	-1.	7 2 6	6 2 5	8.80E-04	7.	7.82E-04	11.1	2.87E-02	-7.19E-04	-3.44E-05
1496.46004	-8.	6 3 3	5 3 2	6.48E-04	4.	6.29E-04	3.0	2.54E-02	-3.96E-04	3.63E-05
1497.22215	6.	7 1 6	6 1 5	9.61E-04	2.	9.22E-04	4.0	3.13E-02	-9.63E-04	3.04E-05
1499.48596	-1.	9 1 9	8 1 8	4.39E-04	14.	4.53E-04	-3.2	2.23E-02	-1.07E-03	9.03E-05
1499.69113	15.	9 0 9	8 0 8	5.12E-04	4.	4.55E-04	11.2	2.23E-02	-1.08E-03	9.19E-05
1507.58925	-14.	7 2 5	6 2 4	8.11E-04	10.	7.35E-04	9.3	2.78E-02	-7.13E-04	2.47E-05
1509.75043	17.	8 2 7	7 2 6	5.51E-04	5.	5.01E-04	9.1	2.30E-02	-6.43E-04	1.86E-06
1510.49726	-5.	6 4 3	5 4 2	2.72E-04	7.	2.62E-04	3.8	1.63E-02	-1.56E-04	-5.40E-06
1511.47115	-2.	10 1 10	9 1 9	2.71E-04	5.	2.47E-04	8.8	1.65E-02	-8.94E-04	9.46E-05
1511.57433	-7.	10 0 10	9 0 9	2.62E-04	2.	2.47E-04	5.7	1.65E-02	-8.99E-04	9.54E-05
1511.70709	-7.	8 1 7	7 1 6	6.08E-04	5.	5.62E-04	7.5	2.45E-02	-7.75E-04	3.27E-05

table 10 continued

observed position	o-c	upper J K _a K _c	lower J K _a K _c	observed strength	%s	computed strength	(o-c)%	Z1 ^a	Z2 ^a	Z3 ^a
1513.76457	-1.	7 3 4	6 3 3	4.94E-04	2.	4.71E-04	4.6	2.20E-02	-3.61E-04	4.92E-05
1523.28731	8.	11 1 11	10 1 10	1.27E-04	6.	1.24E-04	2.7	1.17E-02	-7.22E-04	9.42E-05
1523.80487	10.	9 2 8	8 2 7	3.21E-04	4.	2.92E-04	9.0	1.76E-02	-5.36E-04	1.93E-05
1525.18166	3.	8 2 6	7 2 5	4.58E-04	7.	4.49E-04	2.0	2.17E-02	-5.83E-04	2.10E-05
1526.67110	-1.	7 4 4	6 4 3	2.41E-04	3.	2.23E-04	7.6	1.50E-02	-1.29E-04	2.21E-05
1526.82577	5.	7 4 3	6 4 2	2.42E-04	3.	2.23E-04	7.8	1.50E-02	-1.26E-04	2.75E-05
1527.11667	-3.	8 3 6	7 3 5	3.18E-04	5.	3.11E-04	2.2	1.79E-02	-3.21E-04	4.35E-05
*1528.36448	1.	6 5 2	5 5 1	1.47E-04	10.	1.32E-04	10.5	1.15E-02	-5.97E-05	-2.15E-06
1531.59969	0.	8 3 5	7 3 4	3.17E-04	3.	3.06E-04	3.4	1.78E-02	-3.38E-04	3.01E-05
1534.96745	1.	12 0 12	11 0 11	6.33E-05	2.	5.65E-05	10.7	7.99E-03	-5.66E-04	8.97E-05
1537.56547	0.	10 2 9	9 2 8	1.66E-04	15.	1.55E-04	6.7	1.28E-02	-4.24E-04	2.67E-05
1538.79975	2.	10 1 9	9 1 8	1.85E-04	4.	1.62E-04	12.4	1.32E-02	-4.58E-04	3.38E-05
1542.25977	0.	9 2 7	8 2 6	2.24E-04	17.	2.45E-04	-9.5	1.61E-02	-4.49E-04	1.82E-05
1542.79983	16.	9 3 7	8 3 6	2.07E-04	9.	1.83E-04	11.8	1.37E-02	-2.71E-04	3.63E-05
1542.91426	-2.	8 4 5	7 4 4	1.67E-04	4.	1.57E-04	5.9	1.26E-02	-1.33E-04	2.09E-05
1543.31369	0.	8 4 4	7 4 3	1.58E-04	4.	1.57E-04	.6	1.26E-02	-1.35E-04	2.06E-05
*1544.39654	-206.	7 5 2	6 5 1	1.88E-04	9.	1.48E-04	21.1	1.22E-02	-7.13E-05	4.93E-07
1549.81297	2.	9 3 6	8 3 5	1.85E-04	5.	1.76E-04	4.9	1.35E-02	-2.83E-04	2.04E-05
1551.85057	-24.	11 1 10	10 1 9	7.65E-05	16.	7.73E-05	-1.1	9.10E-03	-3.39E-04	3.22E-05
1558.23996	11.	10 3 8	9 3 7	1.18E-04	7.	9.72E-05	17.7	1.00E-02	-2.19E-04	2.58E-05
1559.18221	-3.	9 4 6	8 4 5	9.59E-05	10.	9.70E-05	-1.1	9.95E-03	-1.21E-04	1.81E-05
1560.49849	-9.	8 5 4	7 5 3	5.79E-05	11.	5.95E-05	-2.8	7.77E-03	-5.11E-05	2.13E-06
1560.51419	26.	8 5 3	7 5 2	6.47E-05	3.	5.95E-05	8.0	7.77E-03	-5.11E-05	2.13E-06
1564.33144	9.	12 2 11	11 2 10	3.75E-05	3.	3.42E-05	8.8	6.06E-03	-2.38E-04	2.76E-05
1564.78136	0.	12 1 11	11 1 10	4.05E-05	5.	3.44E-05	15.0	6.08E-03	-2.45E-04	2.93E-05
1568.11791	-14.	10 3 7	9 3 6	9.69E-05	2.	9.08E-05	6.3	9.74E-03	-2.20E-04	1.43E-05
1573.41708	2.	11 3 9	10 3 8	4.82E-05	8.	4.71E-05	2.4	7.01E-03	-1.69E-04	1.45E-05
1574.43146	4.	11 2 9	10 2 8	5.88E-05	7.	5.51E-05	6.2	7.64E-03	-2.24E-04	1.38E-05
1575.41885	24.	10 4 7	9 4 6	5.26E-05	6.	5.38E-05	-2.3	7.42E-03	-1.01E-04	1.54E-05
1577.15325	-4.	10 4 6	9 4 5	5.38E-05	5.	5.35E-05	.5	7.41E-03	-1.05E-04	1.29E-05
1577.40740	18.	13 2 12	12 2 11	1.46E-05	6.	1.43E-05	2.2	3.92E-03	-1.70E-04	2.47E-05
1586.21629	0.	11 3 8	10 3 7	4.06E-05	12.	4.19E-05	-3.3	6.63E-03	-1.61E-04	1.01E-05
1588.16210	-9.	12 3 10	11 3 9	2.06E-05	3.	2.10E-05	-2.1	4.70E-03	-1.22E-04	6.43E-06
1590.42621	14.	14 1 13	13 1 12	7.39E-06	10.	5.54E-06	25.0	2.45E-03	-1.18E-04	2.12E-05
1591.55843	2.	11 4 8	10 4 7	3.44E-05	12.	2.71E-05	21.2	5.27E-03	-7.95E-05	1.26E-05
1593.00619	-16.	10 5 5	9 5 4	2.28E-05	1.	2.38E-05	-4.6	4.92E-03	-4.06E-05	3.92E-06
*1596.09547	0.	9 6 3	8 6 2	3.06E-05	10.	2.47E-05	19.2	4.99E-03	-1.73E-05	1.56E-07
1603.82872	-6.	13 2 11	12 2 10	9.68E-06	7.	9.05E-06	6.5	3.09E-03	-9.47E-05	9.85E-06

a. the computed strength = $(Z1 + Z2 + Z3)^2$ where Z1 is the contribution due to no interactions while Z2 and Z3 are due to Fermi and Coriolis-type interactions, respectively.

positions in cm⁻¹

o-c, observed minus computed line positions $\times 10^5$. The computed values are derived from the energy levels given in Table 2

%s are the estimated uncertainties in the measured line strengths in percent.

(o-c)%, observed minus computed line strength values given in percent. Computed value are derived from constants obtained in this work and given in Table 5

*asterisks denote doubled absorptions with the quantum assignment given for one of the transitions.

The strength given represents the sum of the strengths of the two comparable transitions.

PR indicates that the transition involves strong Coriolis coupling with a level in the (100) state.

Strengths normalized to 99.9% HD¹⁶O.

Table 11. Line positions and strengths ($\text{cm}^{-2}/\text{atm.}$ at 296K) of the B-type transitions of the (100)-(010) band of HD^{16}O .

observed position	o-c	upper J K _a K _c	lower J K _a K _c	observed strength	t _s	computed strength	(o-c) [#]	Z1 ^a	Z2 ^a	Z3 ^a
1160.99121	-5.	4 1 4	5 2 3	2.08E-05	15.	2.26E-05	-8.7	-5.87E-04	5.37E-03	-2.43E-05
1177.24395	-21.	2 2 1	3 3 0	5.11E-05	22.	6.11E-05	-19.5	-9.98E-04	8.81E-03	4.44E-06
1197.83099	-16.	4 1 3	5 2 4	3.36E-05	10.	3.78E-05	-12.4	-1.17E-03	7.42E-03	-1.10E-04
1205.35968	-7.	8 1 8	8 2 7	2.10E-05	21.	2.00E-05	4.6	9.18E-04	-5.32E-03	-7.31E-05
1209.29725	-14.	3 1 2	4 2 3	4.45E-05	8.	5.44E-05	-22.2	-1.33E-03	8.77E-03	-7.44E-05
1212.12226	-14.	2 1 2	3 2 1	6.47E-05	12.	6.22E-05	3.9	-1.24E-03	9.14E-03	-1.59E-05
1221.75365	-19.	2 1 1	3 2 2	7.24E-05	16.	7.16E-05	1.2	-1.48E-03	9.98E-03	-3.71E-05
1235.27566	-20.	1 1 0	2 2 1	8.38E-05	5.	8.75E-05	-4.4	-1.65E-03	1.10E-02	0.00E+00
1235.99896	-30.	5 1 5	6 0 6	5.91E-05	9.	5.01E-05	15.2	1.92E-03	-9.43E-03	4.34E-04
1236.67684	-33.	7 0 7	7 1 6	4.30E-05	18.	3.54E-05	17.7	1.39E-03	-7.25E-03	-8.37E-05
1240.79973	-19.	4 0 4	5 1 5	8.21E-05	5.	8.13E-05	1.0	-2.13E-03	1.14E-02	-3.01E-04
1248.54535	-3.	4 1 4	4 2 3	7.53E-05	5.	7.12E-05	5.4	1.70E-03	-1.00E-02	-8.59E-05
1252.10421	1.	3 0 3	4 1 4	1.11E-04	7.	9.80E-05	11.7	-2.26E-03	1.24E-02	-2.12E-04
1263.45689	3.	2 0 2	3 1 3	1.05E-04	5.	1.07E-04	-1.8	-2.30E-03	1.28E-02	-1.28E-04
1268.88948	-9.	5 0 5	5 1 4	8.70E-05	4.	8.79E-05	-1.0	2.30E-03	-1.16E-02	-9.34E-05
1269.41480	-21.	3 1 2	3 2 1	9.18E-05	33.	8.36E-05	8.9	2.15E-03	-1.12E-02	-6.75E-05
1269.70113	-19.	4 1 3	4 2 2	8.10E-05	8.	8.61E-05	-6.3	2.41E-03	-1.16E-02	-7.25E-05
1275.41044	-23.	1 0 1	2 1 2	1.01E-04	5.	1.02E-04	-1.1	-2.25E-03	1.24E-02	-5.53E-05
PR1283.87965	-21.	6 3 3	7 2 6	8.44E-05	8.	8.08E-05	4.2	2.41E-04	-1.10E-03	9.85E-03
1286.09072	-40.	2 1 2	3 0 3	4.81E-05	26.	5.03E-05	-4.6	2.00E-03	-9.28E-03	1.87E-04
1290.51193	-11.	3 0 3	3 1 2	1.78E-04	10.	1.58E-04	11.3	3.07E-03	-1.56E-02	-8.37E-05
1296.85233	6.	2 0 2	2 1 1	1.97E-04	9.	1.63E-04	17.2	3.08E-03	-1.58E-02	-7.22E-05
1300.71575	-11.	1 0 1	1 1 0	1.24E-04	6.	1.26E-04	-1.3	2.67E-03	-1.38E-02	-5.63E-05
1303.53349	-10.	1 1 1	2 0 2	2.92E-05	3.	2.84E-05	2.7	1.57E-03	-6.99E-03	9.35E-05
1308.66292	-8.	4 1 4	3 2 1	1.36E-05	10.	1.27E-05	6.5	8.11E-04	-4.30E-03	-7.48E-05
1333.74998	15.	2 0 2	1 1 1	5.75E-05	6.	5.15E-05	10.5	1.97E-03	-9.04E-03	-1.02E-04
1343.38374	1.	3 1 2	3 0 3	7.96E-05	9.	8.16E-05	-2.5	3.61E-03	-1.26E-02	1.18E-05
1362.10525	-7.	2 1 2	1 0 1	8.42E-05	5.	8.69E-05	-3.2	-3.33E-03	1.25E-02	1.61E-04
1365.69981	-27.	4 0 4	3 1 3	1.40E-04	15.	1.26E-04	10.2	3.71E-03	-1.46E-02	-2.97E-04
1380.56921	-3.	5 0 5	4 1 4	1.31E-04	5.	1.33E-04	-1.8	4.21E-03	-1.54E-02	-3.94E-04
1382.63176	4.	4 1 4	3 0 3	1.34E-04	1.	1.23E-04	8.6	-4.29E-03	1.50E-02	3.58E-04
1392.00912	-3.	5 1 5	4 0 4	1.26E-04	5.	1.25E-04	1.0	-4.54E-03	1.53E-02	4.43E-04
1393.72957	-3.	2 2 1	1 1 0	2.93E-05	5.	2.94E-05	-4	-3.13E-03	8.42E-03	1.29E-04
1394.39957	15.	6 0 6	5 1 5	1.17E-04	4.	1.23E-04	-5.5	4.39E-03	-1.50E-02	-4.70E-04
PR1398.71724	15.	6 4 2	6 3 3	5.42E-05	5.	5.80E-05	-7.1	1.02E-03	-1.41E-03	-7.23E-03
1401.55443	-4.	6 1 6	5 0 5	1.21E-04	7.	1.16E-04	4.2	-4.57E-03	1.48E-02	5.05E-04
1421.91126	-13.	8 1 8	7 0 7	8.03E-05	7.	7.52E-05	6.3	-4.07E-03	1.22E-02	5.42E-04
1432.58059	-1.	9 1 9	8 0 8	6.14E-05	14.	5.33E-05	13.2	-3.61E-03	1.04E-02	5.15E-04
PR1437.12781	13.	4 2 2	3 1 3	1.01E-04	14.	1.07E-04	-5.9	-2.55E-03	7.80E-03	5.09E-03
PR1481.18306	7.	6 3 3	5 2 4	1.43E-04	3.	1.52E-04	-6.2	-2.33E-03	4.07E-03	1.06E-02

a. the computed strength = $(Z1 + Z2 + Z3)^2$ where Z1 is the contribution due to no interactions while Z2 and Z3 are due to Fermi and Coriolis-type interactions, respectively.

positions in cm^{-1}
o-c, observed minus computed line positions $\times 10^5$. The computed values are derived from the energy levels given in Table 2

are the estimated uncertainties in the measured line strengths in percent.

(o-c)[#], observed minus computed line strength values given in percent. Computed value are derived from constants obtained in this work and given in Table 5.

*asterisks denote doubled absorptions with the quantum assignment given for one of the transitions.

The strength given represents the sum of the strengths of the two comparable transitions.

PR indicates that the transition involves strong Coriolis coupling with a level in the (020) state.

Strengths normalized to 99.9% HD^{16}O .

Table 12. Line positions and strengths ($\text{cm}^{-2}/\text{atm.}$ at 296K) of the A-type transitions of the (100)-(010) band of HD^{16}O .

observed position	o-c	upper J K _a K _c	lower J K _a K _c	observed strength	ts	computed strength	(o-c) ^a	Z1 ^a	Z2 ^a	Z3 ^a
1150.04176	17.	9 1 8	10 1 9	1.33E-05	12.	1.47E-05	-10.9	1.23E-03	2.48E-03	1.33E-04
PR1171.58838	-27.	6 4 2	7 4 3	3.94E-05	3.	3.68E-05	6.6	8.25E-04	1.68E-03	-8.57E-03
1180.70240	-36.	7 1 6	8 1 7	4.20E-05	11.	4.99E-05	-18.9	2.30E-03	4.64E-03	1.26E-04
PR1182.38740	9.	6 3 3	7 3 4	1.29E-04	6.	1.18E-04	8.2	1.63E-03	3.01E-03	6.24E-03
1191.09550	2.	8 0 8	9 0 9	6.74E-05	15.	6.98E-05	-3.6	2.25E-03	5.65E-03	4.56E-04
1191.34903	-21.	8 1 8	9 1 9	5.87E-05	8.	6.92E-05	-17.9	2.24E-03	5.61E-03	4.69E-04
1196.76370	9.	6 1 5	7 1 6	7.59E-05	8.	8.29E-05	-9.3	2.97E-03	6.02E-03	1.08E-04
1199.70472	3.	6 2 5	7 2 6	5.67E-05	11.	6.22E-05	-9.7	2.55E-03	5.10E-03	2.35E-04
1204.79312	-7.	7 0 7	8 0 8	9.77E-05	10.	1.08E-04	-10.7	2.88E-03	7.06E-03	4.60E-04
1205.25150	-1.	7 1 7	8 1 8	1.03E-04	4.	1.06E-04	-3.1	2.85E-03	6.97E-03	4.87E-04
1213.48940	2.	5 1 4	6 1 5	1.27E-04	12.	1.26E-04	.6	3.66E-03	7.49E-03	8.45E-05
1215.88740	-16.	5 2 4	6 2 5	8.51E-05	5.	8.59E-05	-.9	3.03E-03	5.99E-03	2.42E-04
1218.39601	-23.	6 0 6	7 0 7	1.64E-04	3.	1.57E-04	4.5	3.55E-03	8.53E-03	4.35E-04
1219.17515	34.	6 1 6	7 1 7	1.69E-04	8.	1.52E-04	10.3	3.49E-03	8.34E-03	4.79E-04
PR1226.02480	-6.	4 2 2	5 2 3	1.53E-04	6.	1.50E-04	1.9	3.39E-03	6.27E-03	2.59E-03
1230.77256	4.	4 1 3	5 1 4	1.70E-04	5.	1.72E-04	-1.4	4.27E-03	8.80E-03	6.01E-05
1231.93567	-14.	5 0 5	6 0 6	2.21E-04	3.	2.11E-04	4.4	4.22E-03	9.94E-03	3.77E-04
1232.14225	12.	4 2 3	5 2 4	1.13E-04	6.	1.05E-04	6.9	3.39E-03	6.63E-03	2.37E-04
1233.14674	-2.	5 1 5	6 1 6	2.04E-04	4.	1.99E-04	2.3	4.10E-03	9.58E-03	4.44E-04
1245.07705	8.	3 2 1	4 2 2	9.89E-05	7.	1.10E-04	-11.0	3.51E-03	6.41E-03	5.59E-04
1245.54506	-11.	4 0 4	5 0 5	2.75E-04	2.	2.64E-04	4.1	4.81E-03	1.11E-02	2.94E-04
1248.41183	-3.	3 2 2	4 2 3	1.05E-04	6.	1.08E-04	-3.2	3.49E-03	6.70E-03	2.14E-04
1259.48052	-14.	3 0 3	4 0 4	3.06E-04	3.	2.98E-04	2.7	5.22E-03	1.18E-02	2.01E-04
1261.33161	-11.	3 1 3	4 1 4	2.59E-04	8.	2.56E-04	1.2	4.88E-03	1.08E-02	3.05E-04
1263.23554	-10.	2 2 0	3 2 1	7.68E-05	4.	7.93E-05	-3.3	3.07E-03	5.61E-03	2.26E-04
1264.62915	3.	2 2 1	3 2 2	7.76E-05	3.	8.04E-05	-3.7	3.06E-03	5.74E-03	1.62E-04
1266.12402	-23.	2 1 1	3 1 2	2.01E-04	4.	2.06E-04	-2.4	4.67E-03	9.66E-03	1.60E-05
1273.99448	-2.	2 0 2	3 0 3	3.15E-04	4.	2.98E-04	5.4	5.32E-03	1.18E-02	1.15E-04
PR1281.65322	-32.	6 4 2	6 4 3	2.15E-04	2.	2.24E-04	-4.3	2.52E-03	1.73E-03	1.07E-02
*1285.44180	168.	4 4 1	4 4 0	8.85E-05	9.	1.00E-04	-13.3	5.22E-03	4.65E-03	1.51E-04
1286.06530	-38.	6 2 5	6 2 4	1.42E-05	6.	1.76E-05	-24.1	2.51E-03	2.04E-03	-3.49E-04
1289.12147	-21.	1 0 1	2 0 2	2.64E-04	8.	2.47E-04	6.4	4.95E-03	1.07E-02	4.60E-05
1289.82249	-9.	1 1 1	2 1 2	1.55E-04	5.	1.58E-04	-1.8	4.05E-03	8.40E-03	1.08E-04
1297.85727	-7.	5 3 2	5 3 3	8.99E-05	7.	8.29E-05	7.7	3.67E-03	3.10E-03	2.33E-03
1298.70738	-19.	4 3 2	4 3 1	7.23E-05	7.	6.12E-05	15.3	4.32E-03	4.28E-03	-7.77E-04
1299.73955	-1.	3 1 3	3 1 2	4.52E-05	1.	4.61E-05	-2.0	2.82E-03	4.27E-03	-3.00E-04
1300.24105	6.	3 3 1	3 3 0	1.24E-04	8.	1.12E-04	9.9	5.06E-03	5.80E-03	-2.88E-04
PR1300.29190	-17.	3 3 0	3 3 1	1.55E-04	8.	1.55E-04	0.0	5.06E-03	5.79E-03	1.60E-03
1304.63852	-8.	0 0 0	1 0 1	1.44E-04	3.	1.42E-04	1.1	3.86E-03	8.07E-03	0.00E+00
1308.52968	20.	3 2 2	3 2 1	1.00E-04	5.	1.09E-04	-8.7	4.60E-03	6.06E-03	-2.39E-04
1310.88723	-8.	2 2 1	2 2 0	1.94E-04	3.	1.93E-04	.6	5.66E-03	8.38E-03	-1.49E-04
1311.56956	-12.	2 2 0	2 2 1	1.98E-04	2.	1.93E-04	2.6	5.65E-03	8.46E-03	-2.14E-04
1311.86531	4.	3 2 1	3 2 2	1.10E-04	4.	1.02E-04	7.5	4.58E-03	6.24E-03	-7.39E-04
1320.66573	-14.	1 1 0	1 1 1	1.79E-04	5.	1.82E-04	-1.4	4.65E-03	8.54E-03	2.87E-04
1325.54897	-16.	2 1 1	2 1 2	8.52E-05	4.	8.55E-05	-.3	3.42E-03	5.79E-03	3.65E-05
1332.84617	8.	3 1 2	3 1 3	4.64E-05	34.	5.02E-05	-8.2	2.80E-03	4.22E-03	7.13E-05
1345.84619	-26.	2 1 2	1 1 1	1.72E-04	4.	1.63E-04	5.0	4.74E-03	8.23E-03	-1.85E-04
1350.00870	0.	2 0 2	1 0 1	2.54E-04	5.	2.61E-04	-2.7	5.77E-03	1.05E-02	-1.55E-04
1363.64800	7.	3 0 3	2 0 2	3.08E-04	4.	3.21E-04	-4.3	6.71E-03	1.15E-02	-2.76E-04
1366.24158	8.	3 1 2	2 1 1	2.28E-04	2.	2.27E-04	.2	5.86E-03	9.32E-03	-9.25E-05
1370.80049	-11.	4 2 3	3 2 2	1.18E-04	6.	1.18E-04	.1	4.79E-03	6.32E-03	-2.42E-04
PR1375.59689	-40.	6 4 2	5 4 1	6.67E-05	11.	5.02E-05	24.7	1.53E-03	1.52E-03	4.04E-03
1380.86031	28.	4 1 3	3 1 2	1.94E-04	11.	2.36E-04	-21.7	6.29E-03	9.20E-03	-1.33E-04
1384.19213	3.	5 2 4	4 2 3	1.24E-04	9.	1.18E-04	5.0	5.03E-03	6.14E-03	-3.18E-04
1384.63264	-5.	5 1 5	4 1 4	2.56E-04	4.	2.56E-04	.2	6.82E-03	9.87E-03	-7.03E-04
1389.27882	-21.	6 3 4	5 3 3	3.83E-05	2.	3.68E-05	3.9	3.19E-03	3.14E-03	-2.65E-04
1394.56780	7.	5 1 4	4 1 3	1.90E-04	4.	2.05E-04	-7.7	6.20E-03	8.28E-03	-1.79E-04
1396.80918	-4.	6 1 6	5 1 5	2.09E-04	3.	2.12E-04	-1.5	6.56E-03	8.87E-03	-8.62E-04
1397.00771	-11.	6 2 5	5 2 4	9.85E-05	6.	9.89E-05	-.4	4.86E-03	5.46E-03	-3.74E-04
1399.14456	-11.	6 0 6	5 0 5	2.05E-04	5.	2.29E-04	-11.6	6.71E-03	9.21E-03	-7.91E-04
1407.20717	5.	6 1 5	5 1 4	1.49E-04	4.	1.55E-04	-4.0	5.74E-03	6.93E-03	-2.27E-04
1409.23419	9.	7 2 6	6 2 5	7.53E-05	2.	7.32E-05	2.8	4.42E-03	4.55E-03	-4.09E-04
1415.10697	-35.	8 3 6	7 3 5	1.99E-05	18.	2.04E-05	-2.5	2.60E-03	2.15E-03	-2.27E-04
1418.48922	4.	7 2 5	6 2 4	6.65E-05	7.	6.97E-05	-4.8	4.22E-03	4.22E-03	-9.12E-05
1418.65633	-7.	7 1 6	6 1 5	9.92E-05	8.	1.05E-04	-5.3	5.03E-03	5.47E-03	-2.75E-04

table 12 continued

observed position	o-c	upper J K _a K _c	lower J K _a K _c	observed strength	computed strength	(o-c)†	Z1 ^a	Z2 ^a	Z3 ^a
1420.87900	-2.	8 2 7	7 2 6	4.91E-05	8. 4.87E-05	.9	3.81E-03	3.59E-03	-4.23E-04
1421.17295	22.	8 0 8	7 0 7	1.17E-04	5. 1.11E-04	4.7	5.34E-03	6.27E-03	-1.05E-03
1432.18911	-22.	9 0 9	8 0 8	6.90E-05	2. 6.88E-05	.3	4.51E-03	4.88E-03	-1.09E-03
PR1447.66512	-20.	4 2 2	3 0 3	4.88E-05	10. 5.89E-05	-20.8	9.07E-04	-5.78E-04	7.35E-03
1454.15176	-36.	11 0 11	10 0 10	2.49E-05	7. 2.02E-05	18.9	2.88E-03	2.63E-03	-1.02E-03
PR1474.31832	22.	6 3 3	6 1 6	9.72E-05	14. 8.58E-05	11.8	-1.78E-04	-3.02E-04	-8.78E-03
PR1514.12429	-7.	6 3 3	5 1 4	2.03E-04	3. 1.88E-04	7.6	6.65E-04	-4.83E-05	1.31E-02
PR1574.10404	-18.	6 4 2	5 2 3	1.78E-04	5. 1.78E-04	-.1	2.79E-04	4.77E-05	-1.37E-02

a. the computed strength = $(Z_1 + Z_2 + Z_3)^2$ where Z_1 is the contribution due to no interactions while Z_2 and Z_3 are due to Fermi and Coriolis-type interactions, respectively.

positions in cm^{-1}
o-c, observed minus computed line positions $\times 10^5$. The computed values are derived from the energy levels given in Table 2

†s are the estimated uncertainties in the measured line strengths in percent.

(o-c)‡, observed minus computed line strength values given in percent. Computed value are derived from constants obtained in this work and given in Table 5.

*asterisks denote doubled absorptions with the quantum assignment given for one of the transitions.

The strength given represents the sum of the strengths of the two comparable transitions.

PR indicates that the transition involves strong Coriolis coupling with a level in the (020) state.
Strengths normalized to 99.9% HD¹⁶O.